NONCOMPLIANCE, MONITORING AND THE ECONOMIC THEORY IN CARBON TRADING MARKET

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ABSTRACT

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Supervisor: M.E. Fulton

Addressing climate change is a major undertaking. Agricultural soil has the potential to assist in decreasing the concentration of GHGs in the atmosphere by storing CO_2 in the soil. Carbon offset markets have been suggested as a cost effective means of reducing GHG emissions. Farmers can increase their soil sink potential by applying Beneficial Management Practices (BMPs) that enhance carbon sequestration through improvements to soil, nutrient and livestock management practices (Fulton et. al., 2005). Whether or not a market for carbon offsets will emerge depends on a number of factors which mainly are related to the profitability of the BMPs and the costs of implementing a carbon contract. Provided that a market for carbon offsets emerges, the effectiveness of the market depends, in part, on the degree to which buyers and sellers in the market comply with the terms of the contracts they sign. The resource costs associated with monitoring and verification may result in incomplete monitoring. As long as monitoring is not perfect, non-compliance will be an issue.

The analysis that will be performed in this thesis introduces non-compliance in the economic analysis of carbon-offset market. The purpose of this work is to examine the overall cost effectiveness of the carbon-offset market when introducing non-compliance.

Firstly the theoretical model investigates the incentives for different farmers to participate in the carbon offsets market as well as incentives for engaging in cheating. The model recognizes farmers' heterogeneity with respect to cost differences and examines the economic determinants of farmers' non-compliance as well as the consequences of non-compliance on the performance of the carbon-offset market. Results support the standard finding that the extent of producers' non-compliance

decreases with an increase in the audit probability and/or an increase in the penalty per unit of non-compliance. In addition, the number of producers participating in the carbon offsets market is shown to increase with an increase in the carbon-offset price.

The analysis then introduces intermediaries in the market that will take care of trading carbon offsets as well as monitoring producers. The traders' role in this study is played by an IOF (investor owned-firm) or a PA (producers' association). Within the IOF, the analysis focuses on the monopoly and oligopoly structures. The key role of the traders is to guarantee, based on the amount of monitoring that is undertaken, that the emitters purchase only carbon offsets that actually correspond to sequestered carbon. The analysis then examines three cases for the group that monitors farmers' compliance – a group owned by for-profit traders, a government-run agency and a group owned by the PA trader. This part of the thesis examines what impact the involvement of the traders in the carbon-offset market has on non-compliance, as well as how the structure of the monitoring group affects non-compliance and the amount of carbon offsets traded in the market. The results of the analysis show that the monitoring groups always undertake sufficient monitoring to ensure that full compliance is achieved – thus, while non-compliance is possible, it does not occur in equilibrium. The finding suggests that the formation of a government monitoring agency can potentially increase traded output and lower the price paid by emitters, still these changes are likely to be small, particularly when the trading sector is monopolistic. The overall analysis in this chapter shows that the optimal amount of enforcement, and as a result the cost effectiveness of a carbon-offset market, depends on the nature of the organization that undertakes the enforcement.

The next consideration of the thesis is the heterogeneity attributed to the timing of sequestration by different farmers. The analysis focuses on the carbon offsets pooling by considering two structures for the aggregator: a for-profit aggregator and a producers' association. Pooling resources enables the farmers to benefit from economies of scale. The pricing schedule used by the aggregator is a two-part tariff. The two-part tariff is used as a way of providing an incentive for the farmers sequestering large amounts of carbon to participate in the pool. The study considers two alternatives for the coefficients that might be used to decide on the amount of carbon offsets to which each farmer will be entitled: default coefficient and custom coefficients. Each situation is modeled in a principal agent framework.

The analysis examines how the aggregator will target the monitoring service for different group of farmers. The investigation reveals that, under different scenarios, a PA or a FPA (for-profit aggregator) might lead to the formation of a heterogeneous pool or a homogeneous pool of each type.

The last issue investigated in this dissertation is the coexistence of a FPA and a PA in the default coefficient case. The analysis show that both aggregator structures can exist together in the market in the same time if the savings in the monitoring costs made possible by the PA are smaller than the cost of organizing the pool. If this condition is not satisfied the FPA cannot survive in the market and the producers' association will dominate.

In addition to providing a better understanding of how the carbon-offset market may perform when introducing non-compliance, the results of this study can assist in assessing the cost effectiveness of the carbon-offset market when enforcement is undertaken by different organizations. Furthermore, the last consideration of the pooling option might help in selecting which type of pool – a heterogeneous or a homogeneous one – might perform better under different alternatives.

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND AND PROBLEM STATEMENT

The growing amount of greenhouse gases (GHG) in the atmosphere is regarded as responsible for climate change and global warming. In response to increased GHG emissions and in an attempt to reduce them, countries have entered into international agreements such as the Kyoto Protocol (KP), which came into effect on February 16, 2006. The Protocol requires Annex B countries to reduce their emissions of six greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) by at least 5 percent below 1990 levels over the first commitment period 2008-2012. A key feature of the KP is its use of market based instruments to deal with carbon emissions. The Protocol allows for the use of three flexible implementation mechanisms: emissions trading (ET), Joint Implementation (JI) and the Clean Development Mechanism (CDM) (IPCC, 2007).

The treatment of carbon sinks – i.e., the sequestering of carbon rather than a reduction in its production – was left open during Kyoto negotiations. The negotiating parties reached a compromise on this issue during the Conference of Parties in Bonn (July 2001) by allowing a substantial credit to Australia, Canada, New Zealand, Japan and Russia for carbon dioxide sinks (Böhringer, 2004). The subsequent COP7 in Marrakech (November 2001) approved carbon sinks to be used as a means of carbon reduction by the Annex B countries.

A sink is defined as any process that removes CO_2 from the atmosphere (United Nations Framework Convention on Climate Change, 1992). Forests and agricultural soil have the potential to assist in decreasing the concentration of GHGs in the atmosphere by storing CO_2 in soil or in trees. Farmers can increase their soil sink potential by applying Best Management Practices (BMPs) that enhance carbon sequestration through improvements to soil, nutrient and livestock management practices (Fulton et. al., 2005), while forest managers can enhance carbon sequestration through afforestation, reforestation and forest management. Each unit of carbon stored in the soil or trees can be used to offset one unit of emission released from large final emitters (LFEs). If these units can be verified and certified, they can be sold as carbon offsets or credits in a carbon-offset market.

Allowing the trading of carbon offsets is one of the institutional innovations of Kyoto. Carbon-offset markets have been suggested as a cost effective means of reducing GHG emissions (Vercammen, 2002, Bloomfield et. al., 2003). An offset system can increase the efficiency of meeting emission targets by allowing entities with potential GHG sequestration capabilities to supply offset credits to those that are required to reduce GHG emissions. This option offers greater flexibility in achieving emission reductions and hence the possibility of reaching environmental goals at a lower cost than would be possible if the countries did not have this alternative.

About half of Canada's total GHG emissions by 2010 is anticipated to be released from LFEs (Government of Canada, 2005a). Based on their historical emissions, the level of production and an emission intensity factor, the government could be expected to allocate a large portion of initial permits to LFEs. Each permit gives LFEs the right to emit one unit of emission; LFEs will be allowed to trade these permits. High cost companies can meet their additional permit requirements by purchasing permits from LFEs with lower abatement costs. Permits can be expected to be traded until the point where the marginal abatement costs of all traders will be equalized. It is this cost equalization aspect that makes permit trading more cost-efficient than regulatory approaches. Provided that sinks will be eligible as an option, LFEs can use offset credits as well to address their emission potential.

Although both forests and agricultural soil can serve as sinks, the focus of this work will be on soil carbon offsets created as result of adapting BMPs in agriculture under contract. Whether or not the market for carbon offsets will emerge depends on a number of factors which mainly are related to the profitability of the BMPs and the costs of implementing a carbon contract. BMPs build up organic matter in the soil. Adoption of these practices brings a number of environmental and economic benefits such as: improving soil quality and increasing productivity, improving moisture retention and decreasing irrigation needs, and decreasing soil degradation and erosion. Because of the economic benefits, farmers have incentives to adopt BMPs voluntarily. In addition, they may find an incentive to adopt these practices in order to participate in carbon-offset market. Whether or not farmers will produce carbon offsets by applying BMPs under a sequestration contract depends on the net benefits of such an undertaking.

Provided that a market for carbon offsets emerges, the effectiveness of the market depends, in part, on the degree to which buyers and sellers in the market comply with the terms of the contracts they sign. Compliance, however, should not be presumed. Each tonne of emission reduced or offset created has a value that is equal to the price of a permit or a credit. This value can create an incentive for LFEs to underreport their actual emissions and/or for sink generators to overreport the carbon offsets created from their emission reducing actions.

Non-compliance will be an issue as long as monitoring is imperfect. The possibility of non-compliance arises because it is costly to determine the actions of LFEs or farmers. Because of this cost, farmers, as well as LFEs, are in a position to misreport. The monitoring and verification costs vary depending on the frequency of monitoring and verification, accuracy of measurement, the quantification techniques employed and the size of the contract.

Given the above considerations, it is important to explore how the carbon offset market will be affected by non-compliance on both sides. What role will market intermediaries play in order to guarantee that the carbon credits purchased by LFEs are legitimate? Which organizational structure is more efficient in trading and monitoring? What is the impact of heterogeneity in the cost of providing carbon offsets? What is the likelihood of a homogeneous or a heterogeneous pool being formed in the carbon offset market? How do the various coefficients that might be used to convert the land management practices into carbon sequestration amounts perform relative to each other? This study tries to answer these questions.

1.2 Objectives of the Study

The analysis that will be performed in this thesis introduces non-compliance in the economic analysis of carbon-offset market. The purpose of this work is to examine the overall cost effectiveness of the carbon-offset market when non-compliance on both the demand side (i.e., the LFEs) and the supply side (e.g., agricultural/forestry producers) of the offset market is introduced.

Monitoring and verification has the potential to reduce or deter non-compliance. One prospective approach to address monitoring and verification of the carbon-offsets is the involvement of a trader in the market with the responsibility of undertaking carbon offset trading. Traders will buy carbon offsets offered from farmers and sell verified carbon offsets to LFEs. Even though traders can have different structures – e.g., a for profit firm, governmental agency, an association of LFEs or an association of carbon offset suppliers – this paper will focus on the trading undertaken by for-profit firms and a producers' association.

The analysis then examines three cases for the group that monitors farmer compliance – a governmental run agency, a monitoring group operating on behalf of the for-profit firms and a group operating on behalf of the producers' association. The optimal amount of enforcement is likely to depend on the nature of the organization that undertakes the enforcement since these organizations differ in their objective functions and their access to information. Thus, an important part of the analysis will be an examination of the impact of organizational form on compliance and hence on the cost effectiveness of a carbon-offset market.

Carbon offset pooling is examined under two organizational structures for the aggregator: a for-profit aggregator (FPA) and a producers' association (PA) – both of which are emerging in the carbon offset market. These two organizations differ in a fundamental way – in the FPA case, the aggregator chooses the farmers' type while in the PA case, the farmers choose the type of the pool they form. The FPA chooses the alternative that provides her the highest profit, whereas in the PA case the farmers choose the alternative that provides them the highest benefit. This distinction drives the analysis performed in Chapter VI.

1.3 METHODOLOGY

To achieve the above objectives, this thesis uses different theoretical approaches. The decisions by LFEs and farmers about participation in the carbon offset market are critical to the creation of such a market as well as to the performance of the market. The thesis starts by examining the LFEs' and farmers' behaviour. The LFEs' problem, whether to undertake abatement or to buy carbon offsets, is visited under two scenarios: a full compliance scenario and a scenario in which non-compliance is introduced in the model. The farmers' problem of whether to adopt the beneficial management practices is similarly examined under full-compliance and non-compliance. The LFEs' and the farmers' behaviour are both modeled as decision making under uncertainty.

The study continues by developing models that examine the decisions made by traders and monitoring groups, decisions that are crucial in ensuring the reliability of the offsets' market. In this part of the thesis, the inspection probability is endogenized. The involvement of the intermediaries in the market serves as a guarantee for LFEs that the offsets they are buying are genuine. The monitoring group monitors the land management practice used by the farmers who sign the sequestration contract. The decision of the traders is modeled as a constrained maximization problem. Trading and pricing decisions made by traders are examined as a response to the monitoring group's choice of the auditing rate. A two stage game is used where the decision of the monitoring group is made in the first stage. The game is solved by using backward induction. Both analytical and graphical illustrations are used to perform the analysis. When considering the producers' association as the selected organizational structure, we deal with a pooled pricing strategy. The study then examines the trading and monitoring efficiency by comparing the results obtained when considering different organizational structures for the trader and the monitoring group.

This thesis models separately two types of farmers' heterogeneity: one dedicated to such characteristics of the farmers as management skills, experience, and land type and the other one dedicated to the timing of sequestration. When considering the last mentioned heterogeneity type, the analysis is performed under the two-part tariff pricing strategy.

1.4 ORGANIZATION OF THE STUDY

The rest of the thesis is organized as follows. Chapter two examines the offsets option and the role of agriculture in offsetting net GHG emissions. Chapter three reviews the economics of climate change and non-compliance, and outlines the contribution of this thesis. Chapter four develops a model of the farmer's choice of whether to participate in the carbon-offset market or not. The paper then investigates the impact of introducing non-compliance on the carbon offset market. The paper also examines the role of policy instruments such as audit probabilities and penalties in promoting compliance. The fifth chapter of the thesis investigates the pricing and output decisions of the traders involved in the market to facilitate carbon offset trading. The analysis examines the extent to which different organizational structures undertake monitoring, and the impact of this monitoring on the pricing behaviour. Chapter six considers the heterogeneity attributed to the timing of sequestration by different farmers. This chapter focuses on the carbon offsets pooling by considering two structures for the aggregator: a for-profit aggregator and a producers' association. The analysis considers two alternatives for the coefficients that might be used to decide on the amount of carbon offsets to which each farmer will be entitled. The last chapter summarizes the findings and concludes the thesis.

CHAPTER II

OFFSETS AND THE ROLE OF AGRICULTURE IN OFFSETTING NET GHG EMISSIONS

2.1 INTRODUCTION

Addressing global climate change is one of the biggest challenges of the 21st century. GHGs are largely being accumulated in the atmosphere due to human activities such as industrial, agricultural and household activities. This accumulation is mainly ascribed to activities that involve fossil fuel use, although deforestation is also a contributor. As pointed out by Baumert et. al. (2002), the change in the composition of the atmosphere has increased the average global surface temperature by about 0.6°C (1°F) over the last century. According to the assessment of the Intergovernmental Panel on Climate Change (IPCC, 2007), temperatures are expected to rise between 1.8 and 4°C (3 to 7°F) by the end of 21st century if the trends in GHG accumulation are not amended. Such temperature changes might affect agricultural production, water supply, forests and overall human development. Regional effects such as more frequent and severe droughts or storms, sea level increase, more forest fires, changes in agricultural productivity and water supplies, and damage to vulnerable ecosystems such as coral reefs (WRI, 2006) have already begun to be experienced.

Meeting the climate change challenge requires designing solutions that include developed and developing countries, many sectors of the economy of a country, and options that range from well-known to the novel. The use of the biosphere is becoming increasingly important for countries that are attempting to manage their GHG emissions. According to an FAO (2004) report, the biosphere is considered to be a carbon sink absorbing about 2.8 gigatonnes of C a year, which represents 30 percent of fossil fuel emissions. This sink capacity creates an opportunity for the agricultural and forestry sectors to contribute to GHG reduction in the atmosphere. In particular, the contribution of the agricultural sector in the reduction or removal of GHGs can come from three potential avenues (Weersink et. al.., 2005). Agriculture can be a source of GHGs, mainly in the form of nitrous oxide and methane. The emission of these two gases accounts for 97% of emissions coming from agricultural activities; thus one avenue can be a direct reduction in the emission of these gases. A second alternative would be the production of biofuels and biomass energy which could be used instead of the fossil fuel based energy. This would be one of the novel options that would lower GHG emission levels. The third avenue, which is associated with the role of the agriculture as a sink, would be carbon sequestration by using beneficial management practices such as reduced tillage, reduced summer fallow, crop rotation, increased perennial forages and pasture, and planting shelterbelts. In Canada, it has been estimated that the agriculture sector can generate 10 Mt of CO_2 equivalents per year of offset credits beyond its business-as-usual reductions at a CO_2 equivalent price of $Cdn 10-15/tonne (Gov. of Canada, 2003). The extent to which agriculture can embrace each of these options depends on the incentives that would be created for each of them.

2.2 The Role of BMPs in Carbon Sequestration. Some Potential Co-benefits Related to These Practices

The idea of transferable emission permits was first introduced by Crocker (1966) and Dales (1968). The idea was further developed by Montgomery, 1972; Atkinson & Lewis, 1974, Tietenberg, 1980; Seskin et. al., 1983, and Krupnick, 1986. However, it was the U.S. domestic experience with reducing acid rain that initiated the popularity of emissions trading regimes as mechanisms for environmental pollution control. The success of this U.S. national program in meeting environmental goals in a cost effective manner (USEPA, 2002) encouraged the idea of carbon emissions trading. Still, the inclusion of carbon offsets trading in the emission trading system would be a novelty.

The response to global climate change through the sequestration of carbon in the agricultural sector has varied across countries. The EU ratified the Kyoto Protocol in 2002; however it has chosen not to use soil carbon sequestration in its strategy to reduce GHGs. The EU, Japan and other developing countries have opposed the inclusion of sinks in the Kyoto Protocol by arguing that the uncertainties surrounding the measurement and maintenance of carbon sequestered in the soil would undermine achieving real emission reductions. The choice by the EU not to include sinks in their emissions trading scheme may have been mostly due to the strength of environmental groups who did not want to compromise the achievement of emission reductions (Young et. al., 2006).

Other countries like Canada, United States, and Australia have supported the inclusion of sinks even though the United States has not ratified the Kyoto Protocol. In 2002, the Bush administration announced the Climate Action Plan as an alternative to U.S. ratification of Kyoto. The United States is encouraging the agricultural sequestration of carbon. A modest level of incentives and institutions to support soil carbon sequestration have already emerged. The Chicago Climate Exchange (CCX) was established in 2003 with the goal of building the skills and institutions needed to facilitate the trade in GHG credits. CCX is the world’s first global marketplace for integrating voluntary legally binding emissions reductions with emissions trading and offsets for all six GHGs. However, the rules and regulations governing all aspects of sinks are still being developed by the UNFCC.

As mentioned in the previous section, part of the net emission target can be met by increasing the carbon sequestration into agricultural soils through applying management practices that enhance the sink potential of the soil. The quantity of carbon stored in soils is highly significant, with many of the factors influencing the flow of carbon into and out the soil affected by the management practices applied to the land. Because of the direct benefits that might be associated with beneficial management practices, some farmers are likely to voluntarily adopt them regardless of whether they create carbon offsets that could be sold. In addition to this, increases in education and awareness, technical support, training sessions and demonstration could further increase rates of adoption. Some of the principal land management practices by which agriculture is likely to sequester carbon are discussed below.

Conservation tillage systems, which include *reduced or zero tillage*, reduce the amount and intensity of tillage. Pretty et. al. (2002) consider tillage to be one of the main factors responsible for decreasing carbon stocks in agriculture soils; thus a conservation tillage system would be one of the main land management practices that would increase soil carbon retention. In a zero tillage system, planting is the only process that disturbs the soil. In a reduced tillage system, the tillage equipment that is used helps to maintain a good residue cover (Agriculture and Agri-Food Canada, 2004). Conservation tillage offers several benefits over conventional tillage. A reduced or zero tillage practice increases the accumulation of soil organic matter which gathers as a result of a greater rate of return of plant residues compared to the rate of decomposition of plant residues. The increase of soil organic matter means more carbon is stored in the soil. Other benefits of soil organic matter accumulation include improvements in yield potential, prevention of soil erosion and conservation of soil moisture. In addition, conservation tillage system reduces the time spent on farm operations as well as the fuel requirements since fewer passes are needed under this tillage system.

Reducing summer fallow is another land management practice suggested to increase the soil carbon retention. Summer fallowing can be defined as leaving a field without crop growth for a growing season. Fields may be left fallow in order to conserve soil moisture, control weed problems and/or increase the nutrient availability in the soil. But summer fallow decreases the organic matter level in the soil since fewer residues are returned to the soil. Less soil organic matter means less carbon sequestered in the soil. In addition, the lack of plant residue cover leaves the soil exposed to erosion, which in turn can increase the salinity of the soil, reduce wildlife habitat and lower water quality. Hence, reducing summer fallow can result in improved water quality and in a reduced risk of erosion. Under this scenario, weeds are controlled by using herbicides and soil moisture can be conserved by reducing tillage.

The other extreme to summer fallow practice would be *continuous cropping* in which crops are grown every year with no fallow years in between. The result would be an enhancement in the soil organic matter and in carbon storage. A *crop rotation* would provide additional benefits. A crop rotation would help not only to build organic matter but also to reduce diseases by breaking their cycle, to vary herbicide types in order to reduce the risk of developing herbicide resistance, and diversify the operation in order to lower the production risk. However, a more diverse crop rotation necessitates increased management skills.

Permanent cover is a land management practice that is particularly recommended for areas that are at high risk for such problems as erosion or soil salinity. Permanent cover refers to such practices as *perennial forages* that help to build up soil organic matter, increase carbon storage, prevent erosion and reduce pest problems in subsequent crops.

Planting *shelterbelts* is another management practice that contributes in storing carbon. Co-benefits related to this practice would be a reduction in the risk of wind erosion and a decrease in the evaporation of the soil moisture.

The processes of plant productivity, soil degradation and carbon sequestration are closely linked. Beneficial management practices that increase the organic matter content of the soils typically have a positive impact on air, soil and water quality, as well as improving wildlife habitat. However, shifting from one management practice to another is likely to involve some significant costs. The new practice might require changes in equipment, revising the management of the crop residues and weeds, and modifying the crop rotation in order to prevent pest problems. These factors, as well as the lack of experience or the lack of the initiative for change, might explain why some farmers have not adopted such practices as reduced tillage. Farmers with different characteristics will likely have different incentives to adopt certain land management practice since they incur different transition costs and must incur different costs associated with the new operation. As a result, they might need an extra incentive to switch from one land management practice to another. Such an additional inducement for adoption of these practices might be the involvement in the carbon offset market by supplying carbon credits through sequestration activities. This farmer heterogeneity is a key factor of the model developed in this thesis.

2.3 Some Important Considerations for the Carbon Market

For farmers to participate in the carbon market they must find it economical to both adopt the BMPs and sign a sequestration contract. Signing a sequestration contract means a farmer is now required to complying with the provisions of the contract. The cost of this compliance must be considered when determining which farmers will participate in the carbon offset market.

As Young (2003) indicates in her paper, the amount of carbon that will be sequestered by a farmer depends on the soil type, the history of the land and the particular land management practice that will be applied. This range of factors affecting carbon sequestration makes it difficult to design a standardized contract. The designing and signing of the specialized contracts will add important transaction costs to carbon sequestration contracts. To minimize these costs, it is expected that the government will set out suggested formats for contracts, thus saving the actors some legal costs of full contract creation (Allan & Baylis, 2005). Another alternative that could reduce contracting costs would be a pooling system which is able to spread the additional costs associated with individual contracts. The pooling option is considered in two chapters of this thesis.

The design of the sequestration contracts is complicated by the issue of permanence. The carbon stored in the soil can be released back into the atmosphere if the agricultural practice is changed. The release of carbon can be from natural hazards or from a deliberate change in the practice. If the contract assumes the carbon is sequestered on a permanent basis than a responsibility exists for someone to repurchase the carbon units that are released in the atmosphere. Since the trajectory of the price for carbon offsets is uncertain at the time of signing the contract, the buyers and the sellers face a risk. If the price of carbon offsets is high at the time the replacement of carbon credits is needed, then replacing might become very costly.

Since the carbon sequestered in soil is expected to be left there indefinitely, the decision to sequester carbon is effectively irreversible; this irreversibility reduces the farmers' ability to adjust to a new policy or to withdraw for a better alternative. As a consequence, the option to defer the signing decision has an option value (Vercammen, 2002). Farmers would need to be provided with an option value in order to make the contract profitable. In addition to this option value they might require a premium today in order to cover the extra risk they undertake when they participate in a carbon sequestration scheme.

The replacement of the carbon credits can be done through buying other permanent credits, purchasing insurance (if available) or purchasing temporary credits. The temporary credits are committed only for a specified length of time and after this they expire and need to be replaced. The liability for replacement might be issued to the seller of carbon, the buyer, an independent broker, an insurer, or an aggregator. Several alternatives to address the risk associated with offset reversal have been suggested. These include the insured credits, temporary credits, partial crediting or time delayed crediting, carbon banks, and renting or leasing of carbon offsets. The option chosen to cope with the permanence issue will influence the transaction costs as well as impact the distribution of the costs to the players in the market.

Transaction costs will play a key role in the success or failure of the offsets system. Resources will be needed to encourage farmers to participate in the market as well as to evaluate and certify the carbon credits (Fulton, Çule and Weersink, 2005). Taking into account the cost of these resources is an important consideration. One way of lowering transaction costs is offsets aggregation. This option can offer both lower risk and lower transaction costs.

It has been proposed that the carbon credits created from sequestration as well as the trading of carbon offsets will be counted in the national inventory which has a subcomponent focused on agriculture. The GHG emissions and the soil carbon stock changes will be estimated by the National Carbon and Greenhouse Gas Emission Accounting and Verification System (NCGAVS). As Weersink et. al. (2005) point out, this system will use a variety of information sources such as the Census of Agriculture, industry association data, and satellite imagery. This information will consist of the type of farm activities, the land area allocated to these activities, the level of fertilizer application, and local conditions. The NCGAVS estimations will be based on emission coefficients and conversion coefficients which link the management practices to GHG reductions or carbon sequestrations. These coefficients will be established by using scientific experiments and computer simulation models. Computer models such as the Model Farm Program which takes into account the management practice, the type of soil and the type of crop will be used to determine the level of emissions and carbon sequestration.

The reliability of such models will be evaluated further by undertaking measurements at representative farms and research sites across the country (Agriculture and Agri-food Canada, 2003b). Still, a level of uncertainty exists over the coefficients that will be used to convert particular practices into carbon sequestration amounts (Weersink et. al., 2003). The amount of carbon sequestration will be different in different stages of sequestration. The terrestrial sinks are limited by the ecosystem capability in interaction with the land management system (Lee., H.C. et al., 2003). When applying a sequestering activity, the soil sequestration potential increases in the early stage of sequestration until it reaches a peak in a latter stage and then decreases until the soil becomes saturated. Thus, the stage of sequestration takes on a particular importance in determining the converting coefficients. Farmers may sequester different quantities of carbon at the same point in time for the same land size depending on which sequestration phase they are. The analysis in Chapter VI addresses two types of coefficients that could be used in an offset pool to link the management practice to the carbon sequestration.

Another important consideration for developing a carbon offset trading system is the establishment of the baselines. The baseline refers to the level of GHG emissions or carbon sequestration that occurs in a business as usual (BAU) scenario, which means in the absence of climate change action. The baseline establishes the standards against which the changes can be measured. The actual emission reduction is equal to the difference between the actual emissions and those that occur under the BAU scenario. Offset credits will be issued only for these additional tons of sequestered carbon and only these carbon offsets will be eligible to be traded in the carbon offset market. Establishing the baselines requires information about the economic trends that affect the output of the sequestering activities, historical knowledge of land management practices in certain areas as well as other regional-specific information. A number of methods have been proposed for establishing the baselines such as a case-by-case basis, a generic approach based on regional averages, a dynamic approach which accounts for future changes or trends, and an approach that uses comparison to similar project benchmarks (Government of Canada, 2005b). Each of these approaches will be associated with some costs which will add to the transaction costs of the carbon trading system. The more complicated is the approach, the higher are the associated costs. These higher costs will result in higher transaction costs and a decrease in the attractiveness of the carbon offset trading option.

Lack of additionality has been one of the main sources of criticism of carbon offsets supplied by agriculture through no tillage. For instance, the CCX has been criticized on these groups. As stated from Kollmus et. al. (2008), “there were several documented instances where farmers received carbon offset revenue for practicing no-till agriculture despite the fact that these farmers had been practicing no till for many years already” (Page 70). Rewarding farmers who have been practicing no-till with carbon offsets undermines the integrity of carbon offsets since the buyer of carbon offsets will continue to emit while no further emission reduction is achieved from those farmers. CCX argues that it would be unfair if the farmers who have been engaged in no-tillage practice for many years cannot sell their carbon credits. Addressing this fairness issue would require other measures such as tax/subsidy treatment and discounting of credits (Kollmus et. al. 2008).

The carbon trading system will require some form of monitoring and verification. An offset credit will be granted only for the units of reduction or removal that are genuine. This necessitates the need for a verification of the baselines and the changes in the carbon stock. Because of the value assigned to the carbon offsets in the offsets market, the farmers will have incentive to over report the carbon offsets created from their sequestering activities; thus monitoring and verification is crucial in ensuring farmers' compliance. As long as monitoring is not perfect, non-compliance will be an issue. The non-compliance issue is one of the main issues addressed in this thesis.

The cost of monitoring and verifying the amount of carbon that has been sequestered will be an important component of the transaction costs. One option for minimizing these costs will be a pooling option which makes cost sharing possible. This alternative involves sharing of the fixed costs and enables farmers to benefit from economies of scale present in supplying carbon offsets. A pool can handle large volumes so that per unit monitoring costs can be kept low. This solution, however, leaves open questions about the willingness of farmers with large sequestration potential to participate since they might benefit more from participating in the carbon offset market as independent individuals rather than as part of a pool comprised of other farmers with different sequestration potential.

The free riding issue is one of the main issues explored for the pooling option. In such a setting, farmers have an incentive to shirk on their contribution and free ride on the contribution of others (Harris et. al., 1998). Farmers who free ride attempt to benefit from gains created by the pool without sharing in its costs. This would negatively affect the benefits that farmers who do not shirk can obtain from using the pool option. Hence, the free riding problem is an important consideration that should be taken into account by the pool when making its pricing and monitoring decisions. The last part of Chapter V explores further this case.

2.4 CONCLUSIONS

The global community has recognized the challenge of climate change. Countries are searching for solutions and are taking actions to combat the problem. Agriculture is considered as a potential contributor to the reduction of GHGs. Part of this contribution could come through soil carbon sequestration. This chapter explores the main land management practices that are likely to play a significant role in enhancing soil carbon retention. The adoption of these practices should be supported by policy designs that provide economic benefits to the farmers as well as encourage environmental benefits.

Policy design for agricultural soil carbon sequestration is complicated by such issues as contract design, non-permanence, baseline establishment, and monitoring and verification issues. Each of these issues will have an effect on the incentives required to encourage producers' participation in the offset market and on the success of the offsets system in reducing GHG emission in the most efficient way. These issues are addressed by the research in this thesis.

CHAPTER III

THE ECONOMICS OF CLIMATE CHANGE AND NON-COMPLIANCE

3.1 INTRODUCTION

The problem of climate change has been widely treated by various economists in their research work. This chapter examines how the environmental regulation literature in general and the climate change literature in particular have evolved through the years. Section two focuses on the efficiency properties of market based instruments. Section three examines how this efficiency property is affected when different assumptions are relaxed. Section four concentrates on agri-environmental policies and the farmers' behaviour under these policies. The carbon offsets option and compliance monitoring is the focus of the fifth section. The chapter concludes with an examination of the contribution of this thesis.

3.2 EVOLUTION OF THE ENVIRONMENTAL REGULATION LITERATURE

Since the recognition of environmental problems such as pollution, environmental economics has become an important subject within economics. In an economic context, society's welfare is maximized when social marginal benefit equals social marginal cost. An environmental problem arises when a market failure prevents the equalization of the social marginal benefit with the social marginal cost. Such a situation can occur as a result of an environmental externality such as GHG emissions. In the case of an externality, the private and social costs will diverge. Environmental economics recognizes this divergence between private and social costs. As van Kooten (2004) states, "environmental economics is all about measuring non-market values, determining the deviation between private and social costs, and designing economic incentives (instruments) and institutions to correct the externality" (p. 17).

Common economic instruments used to address a market failure due to an externality are the uniform standards and market incentives.

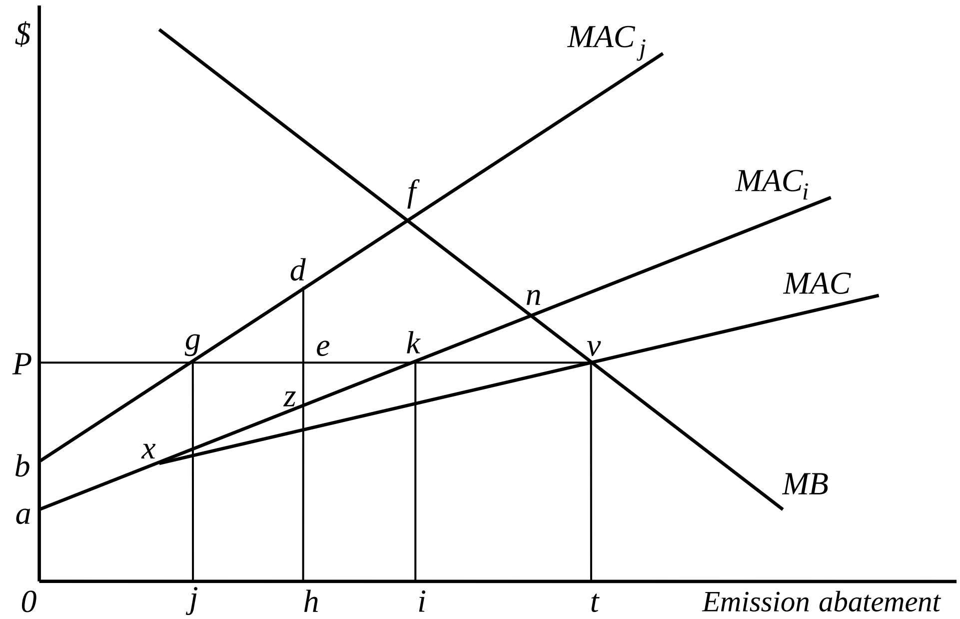
Uniform standards, also referred as the command and control approach, were the most common approach to environmental policies in the 1970s. Basically, the approach consists of setting emission standards and monitoring and enforcing these standards. The emission standards can be performance based standards that specify the level of permissible pollution for each firm or technology based standards that specify the particular pollution control technology that must be used. This conventional approach is a widely understood form of environmental policy but it has some disadvantages. The main drawback of the uniform standards approach is that it gives companies little flexibility in how they can meet the emission targets without being able to respond to differences in local environmental conditions or in their marginal abatement costs (O'Ryan, 2007). The standards are uniformly applied to all firms, requiring the firms with high cost of abatements to meet the same requirements as the firms with low cost of abatement. This requires more resources being used than in the case of having more abatement undertaken by the low cost abaters. Another limitation of this approach is that it discourages the development of innovative technologies to improve the environment. Because of these disadvantages, economists began to explore other possible instruments for addressing environmental problems.

Market based instruments have received wide attention in the literature. This approach allows emitters greater flexibility in the choice of how to satisfy the emission control responsibilities than is possible under the uniform standards approach. The main attractiveness of this alternative is the large potential cost savings that market based instruments promise. Emissions' trading is considered as a major market incentive instrument available to mitigate climate change. Emissions trading can take either the form of permit trading or credit trading and can significantly increase the flexibility with which companies can meet their pollution reduction requirements. In the credit trading case, the government requires each emitter to reduce emissions by a certain amount. Firms that reduce their emission below the required level get credits which can be sold to the other (presumably higher cost abating) firms. By making these credits transferable, the regulator gives emitters the possibility to use the cheapest way of meeting their obligations, even if the cheapest way is managed by another firm. As we will see latter in this thesis, credits can also be created by sequestering carbon in the soil.

Permit trading requires the establishment of an aggregate emissions quota followed by allocation of the rights to pollute which can be traded in the permits market; thus the right to pollute is turned into a traded commodity. As mentioned in the previous chapter, the idea of transferable emission permits to distribute the pollution control burden among firms was first developed by Crocker (1966) and Dales (1968). Montgomery (1972) shows that the tradable permits system (TPS) could be a cost effective policy for controlling air pollution. Since then, a significant literature on TPS has emerged. A number of studies (Atkinson & Lewis, 1974; Tietenberg, 1980; Seskin et. al., 1983; Krupnick, 1986) have compared the costs under a uniform standards approach with those under an economic incentives system; the results of these studies indicate that the costs under the command and control approach are several times those under a market based system. A comprehensive survey of related literature is provided by Tietenberg (1985).

The estimated cost savings in the studies cited above result from the ability to take advantage of the large differentials in abatement costs across polluters. A market incentive system makes it possible to coordinate more efficiently the abatement activity across firms with heterogeneous abatement costs. The market incentive instruments enjoy little advantage if all emitters face similar abatement costs. The cost efficiency of a market incentive instrument versus the uniform standard approach can be illustrated by using Figure 3.1, where the simplest case is considered. Suppose that the two polluters i and j, which are required to reduce their emission, have different marginal abatement costs $MAC_i < MAC_j$. The total emission reduction target is given by $0t$ which is determined by the intersection of the marginal benefit curve with the marginal social cost of abatement $MAC = MAC_i + MAC_j$. Under the uniform standards approach, both firms will be required to reduce emission by the same amount $0h = \frac{0t}{2}$. The cost to the society in this case will be represented by the area $0azh$ plus the area $0bdh$.

Suppose instead that a tradable permit market is employed where the same emission right $0h$ is allocated to each firm. The permits can be traded in the permits market. At the permits trading price P, the low abatement cost firm i is willing to undertake more abatement than is required and to sell the excess emission rights $(0i - 0h)$ to the high abatement cost firm j. The high cost abater finds it more beneficial to undertake abatement only for the amount $0j$ and to buy the permits for the difference $(0h - 0j)$ from the low cost abaters. As we notice, the permit trading continues until the marginal cost of pollution reduction is the same for both emitters. The cost to the society in this case is represented by area $0bgj$ plus the area $0aki$ and is smaller than the cost under a standard. Indeed, the saving to society is given by area gde plus area zek. Since the marketable permits system offers a lower cost to the society, this approach is more cost effective than the command and control approach at achieving a given emission reduction.



Source: Van Kooten, 2004

Figure 3.1. Uniform standards versus TPS to reduce emission

As Milliman and Prince (1989) point out in their paper, another advantage of the economic incentive instruments is the potential to encourage the development of more efficient abatement technologies to improve the environment. The ability to sell permits provides an incentive for firms to invest in pollution abatement technologies. The tradable permit system makes allowance for industrial development as well. New emitters can enter the industry and take care of their pollution in the most efficient way with one of the means being the purchase of permits from the established firms.

The literature supporting the efficiency property of market-based instruments depends on assumptions such as perfect competition in the permit and/or product market, full compliance and enforcement, and zero transaction costs or full information on the part of the firms with respect to abatement costs and permit prices (Fowlie & Perloff, 2004). These are suspect assumptions and raise the issue of robustness of the results obtained when those assumptions are relaxed. Subsequent literature in the environmental economics field has addressed the issues of market power, non-compliance, monitoring, property rights and information problems.

3.3 Robustness of the Efficiency Property in the Tradable Permits Market

The cost efficiency of the TPS in a perfect competition setting is well recognized. However, it is known that the major polluters are typically large firms in highly concentrated industries; thus the product market, as well as the permit market, may not be perfectly competitive. Work by Hahn (1984) explores the issue of market power in the context of markets in transferable property rights. He assumes that only one firm has market power and all the firms are complying. The author shows that the initial permit endowment can influence the price strategy of a firm with market power as well as the equilibrium allocation of permits leading as a result to inefficiencies. He reveals that the degree of inefficiency increases as the permit endowment allocated to the firm with market power increases. These results obtained by Hahn challenge the result obtained earlier by Montgomery (1972) about the cost efficiency of the TPS; these results also indicate that initial distribution of permits is not a pure equity issue.

The theoretical models supporting tradable emission permits have also been challenged by the presence of non-compliance. Malik (1990) appears to be the first to address the issue of imperfect compliance in a TPS. His analysis examines the performance of the tradable permit markets in the presence of non-compliance. He shows how non-compliance affects the equilibrium permit price; he also derives some rather stringent conditions under which the TPS still satisfies the cost efficiency property. However, Malik obtains these results by examining a competitive permit market.

Van Egtern and Weber (1996) extend the works by Hahn and Malik by incorporating both non-compliance and market power in their model. They show how non-compliance is connected to the initial permit endowment. Their main finding is that the initial permit endowment of the firm with market power is crucial in determining the levels of compliance, the permit price and the abatement costs. As in Hahn, it is shown that the initial allocation of permits can be used as a policy instrument to vary the market power in the permits market. The paper shows as well that moving away from perfect competition in the permits market with non-compliance can distort the equilibrium outcomes. This distortion in the efficiency of the permit market was not accounted for in the previous literature.

The relative efficiency of tradable emission permits can also be affected by the presence of transaction costs. Stavin (1995) explores the performance of the tradable emission permit system in the presence of transaction costs. He identifies three potential sources of transaction costs in tradable permit markets: (1) search and information; (2) bargaining and decision; and (3) monitoring and enforcement. The paper provides a body of evidence indicating the prevalence of significant transaction costs in these markets. This evidence includes a lower permit trading level than anticipated by a theoretical model that does not take the related transaction costs into account, the existence of consultants who assist in the search process as well as the existence of commercial brokers that charge considerable fees to facilitate transactions. The main finding of this paper is that the transaction costs increase the cost of controlling pollution by either reducing the trading levels or by adding to the abatement costs, thus reducing the advantage of the tradable permit systems over the uniform standard approach. Another implication of the analysis performed by Stavins is that when marginal transaction costs are nonconstant the equilibrium permit distribution is sensitive to the initial allocation of permits. The suggestion of this analysis is that there is no simple answer in evaluating and choosing the most proper instrument; therefore a case by case comparison of these instruments might be required.

Since Malik (1990) introduced noncompliance in the analysis of tradable permit markets, a sizeable literature on monitoring and enforcement of environmental policies has followed. The literature considers both the monitoring level and the penalty level as the main instruments that might affect compliance behaviour. Increasing monitoring activities as well as raising the penalty may significantly enhance non-compliance deterrence. Keeler (1991) highlights the importance of the penalty structure that firms face as a chief determinant of outcomes in the tradable permit market. His paper considers how a marketable permit system performs relative to a uniform standards system under different shapes of the penalty function facing the firms. He finds that in some circumstances the tradable permits system may result in higher pollution than a uniform standards system.

With perfect monitoring, the tradable permit system is superior to the uniform standards system in providing cost savings (Tietenberg, 1985). It is uncertain whether this least-cost advantage remains when emissions are not perfectly monitored. The performance of tradable permit system under imperfect monitoring is the subject of Montero's work in 2003. The author finds situations in which the uniform standards system can be welfare superior to the tradable permit system. Such situations are ones where the production and abatement costs are negatively correlated or the output and abatement activity interact negatively. In this case, the superiority of the permits policy is no longer clear.

In a more recent paper, Montero (2005) finds that "permits sometimes can provide firms with incentives to choose combinations of output and abatement technologies that may lead to higher aggregate emissions than under standards, something that would not occur if emissions were accurately measured" (p. 657). In this work he also explores the advantages of a hybrid policy that would combine permits and standards. The result of this analysis is that in many cases the hybrid policy will converge to the permits-alone policy but never to the standards-alone policy.

The literature argues that social norms and community pressure might play a significant role in yielding compliance rates. These forms of informal sanctions have been the subject of work by Pargal and Wheeler (1996), Pargal et. al. (1997), and Brooks and Sethi (1997). The findings of these papers support the role that informal regulation can play in inducing compliance. However, the extent to which these forms of informal sanctions can play this role depends on the community income and education level.

Economists suggest self-reporting as one of the innovations that might be used to reduce the need for expensive monitoring. Harford (1987) introduces self-reporting in his study and examines the optimal level of a firm's emission under such a scenario. He finds that imposing stricter self-reporting requirements usually has the effect of reducing pollution, but this is not always the case. The author performs his analysis under different penalty structures and finds it possible that, in some cases, increasing the penalty for failure to report may cause an increase in the emission level.

Malik (1993) studies how self-reporting can affect enforcement costs. Self-reporting does not remove the enforcement costs completely since the regulator will undertake the auditing of self-reports. High enforcement costs make policies less effective than desired. The main finding in Malik's paper is that "self-reporting reduces costs when (1) the cost of auditing is high, (2) the maximum feasible fine is low, or (3) the desired effort level is high" (p. 253). Malik shows that in other cases self-reporting will be likely to increase costs. It is worthwhile sometimes to lower the penalty for non-compliance, thus trading off some compliance for more reliable self-reporting.

Other papers focusing on enforcement issues related to self-reporting are those by Innes (1999a and 1999b). A broad survey of the economics literature on monitoring and enforcement is provided by Cohen (1999).

The main focus of the literature discussed so far has been on the environmental enforcement policies applied to the industry sector. The next section will be concentrated on the development of the literature on agri-environmental policies and particularly on the compliance monitoring issue.

3.4 Designing Agri-Environmental Policies With Limited Information

Agri-environmental policies have been in place since the mid-1980s. They are typically voluntary in nature and are used to encourage desirable environmental outcomes in the countryside. A sizeable literature has focused on agri-environmental policies and especially on the economic incentives used to implement these policies. Whitby and Saunders (1996) compare two of the instruments that have been developed in the UK to secure conservation goods described as Sites of Special Scientific Interest (SSSI) and

Environmentally Sensitive Areas (ESAs). These instruments are management agreements between the farmers and the conservation agency that modify production activities to benefit the environment. Modifications imply a decrease in the production intensity; therefore the producers should receive enough compensation for the loss they incur in order to forego production options. The authors underline that both instruments involve transaction costs for the producers and the conservation agency which are related to examining the relevant areas of land, negotiating agreements and monitoring compliance. The paper shows that the ESA instrument is more expensive per hectare protected than SSSI.

While the previous work deals with the incentives needed to adopt certain agri-environmental schemes, a further consideration is the examination of the farmers' behaviour once they have joined those schemes. To judge the effectiveness of a policy, we need to be able to determine whether the participating farmers are complying with the provisions of the policy (Russell, 1994). Work by Latacz-Lohmann in 1998 and by Choe and Fraser in 1998 and 1999 have addressed the topic of compliance monitoring in agri-environmental schemes by applying the principal-agent theory. Latacz-Lohmann assumes farmer are risk neutral, while Choe and Fraser allow for risk aversion in their analysis. The policy instruments available to the environmental agency in Choe and Fraser's paper (1999) are the monitoring accuracy and the incentive payment for compliance. They focus their analysis specifically on the relationship between the monitoring accuracy and the costs incurred by the agency during the implementation of the policy when the farmer is risk-neutral and risk-averse. The authors show that the environmental agency faces a trade-off between the monitoring costs and the rewards on delivery of the desired outcomes from farmers.

Ozanne et. al. (2001) further develops the work of Latacz-Lohmann and Choe and Fraser and analyses the economic inefficiencies arising from moral hazard in agri-environmental schemes. Their model recognizes the trade-off between increased environmental benefits and the increased cost of monitoring compliance. The solution of the problem determines the optimal compensation payment, monitoring level and the input abatement. Numerical simulations undertaken in their work support the idea of a decrease in the optimal monitoring with an increase in the farmers risk aversion.

Hart and Latacz-Lohmann (2005) extend the literature by developing a model that accounts for the variation in farmers' compliance costs. The regulator does not have information about the compliance costs of each farmer but it does know the distribution of these costs. The available instruments to the regulator through which he can influence compliance are the compensation payment and the monitoring probability. The authors find that increasing the total compliance target results in an increase in the optimal monitoring probability and payment level. The regulator characterizes farmers as honest or dishonest and this distinction has a significant effect on the policy. Paradoxically, an increase in the proportion of the honest farmers leads to an increase in the total number of cheats. The explanation is that the regulator reduces monitoring if there are more honest farmers; therefore the dishonest farmers are more inclined to cheat.

Farmers' cheating and misrepresentation has been incorporated in the theoretical analysis of agricultural policy performed by Giannakas and Fulton in 2000. They explore the economic effects of misrepresentation and cheating for three stylized policy instruments – output quotas, output subsidies, and a combination of an output quota and a subsidy. The results show that cheating alters the welfare effects of the policy instruments and their efficiency in redistributing income to producers. When cheating and/or misrepresentation occur, output subsidies are a more efficient means of income redistribution than are output quotas. A combination of policy instruments, however, can usually result in a more efficient transfer than any of the policy instruments alone.

In a more recent work, Giannakas and Kaplan (2005) investigate the economic determinants of producer non-compliance with the conservation provisions of the highly erodible lands policy. Producers are considered as heterogeneous and the available policy tools are audits, penalties and farm program payments. They investigate the role of these policy tools in promoting compliance as well as evaluate the effectiveness of the current policy design in inducing adoption of the conservation activity and in deterring producer non-compliance. In particular, they show that an increase in the income transfers to agriculture through commodity and conservation payments will increase the adoption of conservation practices as well as reduce the extent of producer non-compliance.

The focus of next section will be on the literature related to the carbon offsets option and compliance monitoring.

3.5 Carbon Offset Option and Compliance Monitoring

Air quality and pollution issues have been widely treated in the literature. A great volume of literature in the past decade has been focused on the sulphur dioxide scheme which is generally acknowledged as being highly successful (Kete, 1992, 1994; Schmalensee et. al., 1998a, 1998b, 1998c; Stavins, 1998; Ellerman et. al., 1997, 2000). Economists have tried to use the benefits of this experience in schemes intended to mitigate climate change. Since endorsement of the Kyoto Protocol, the climate change literature has been addressing the issue of GHG emissions. Part of this literature has been focused on the use of carbon sinks as a promising option in offsetting emissions.

Work by Mascher (2004) provides an overview of an emission trading scheme (ETS) and the position of offset credits within such a scheme. She talks about the Canadian proposal of establishing an offset trading system and, in parallel, provides an overview of other offset systems throughout the world even though experience with these systems is quite limited.

The opportunity to create offset credits by sequestering carbon in the forests has been addressed in a number of studies. Van Kooten et al (2002) examine the economic aspects of the incentives and institutions needed to motivate landowners to convert their land to plantation forests. Even though tree planting is considered as a cost-effective means for achieving carbon offsets, the results show that there may be some unaccounted transaction costs that increase the costs of afforestation considerably. The survey undertaken in this research provides some insights concerning transaction costs and suggests that transaction costs of getting farmers to adopt tree planting may be substantial and became a significant barrier to afforestation.

Studies by Moulton and Richards (1990), and McCarl and Callaway (1993) have included in their analysis the opportunity costs of foregone agricultural uses and have constructed cost schedules which will help them in identifying promising regions for establishing forests. Parks and Hardie (1995) underline that, in order to be effective in converting agricultural land to forest, a program should take into consideration the discounted opportunity costs of foregone agricultural profits as well as the forest establishment costs. Parks and Hardie's results suggest that the carbon sequestering policies should select marginal agricultural lands based on minimizing costs per ton sequestered. If the selection criterion is the minimum cost per acre, the amount of land enrolled would increase but the amount of carbon sequestered would decrease; thus basing the selection on this criterion would result in less effectiveness in sequestering carbon.

The efficiency of the per-tonne versus per-acre payment schemes is examined by Pautsch et al (2001) for the case of sequestering carbon in the soil by adopting different tillage practices. They reach a similar conclusion with Parks and Hardie in the favor of the per-tonne based payments.

Antle et al (2003) investigate the efficiency of alternative contracts for carbon sequestration in cropland soil. Their research takes into account the spatial heterogeneity of agricultural production systems as well as the costs of implementing efficient contracts which consist of the measurement costs and the on-farm opportunity cost. The analysis shows that the per-hectare contracts are as much as five times more costly than the per-tonne contracts. The results indicate that both the measurement costs and the relative inefficiency of per-hectare contract increase with the degree of spatial heterogeneity. The measurement costs of implementing per-tonne contract are found "to be at least an order of magnitude smaller than the efficiency losses of the per-hectare contract for sampling errors in the range expected to be used in the contracts" (pg 248). The analysis suggests that the contracting parties can achieve a lower total cost with the per-tonne contract than with the per-hectare contract.

To ensure that the GHG reductions are taking place in the quantity claimed, monitoring and verification will be required for the offset projects. The efficiency of the sequestration contract will depend to a significant degree on the costs of monitoring and verification since those activities can be very costly. Monitoring carbon requires specialized equipment, methods and trained personnel which can be expensive to obtain and maintain. Monitoring will be performed for the baselines which serve as a benchmark, as well as for the changes in the carbon stored in the soil or in the forest (MacDicken, 1997). Establishing the right baselines is very important for the credibility of the offset system. Chomitz (1998) points out that the baseline determination depends not only on "the methodology used but also on the set of institutions that keep the application of the methodology honest and reasonable" (p. i).

Work by Brown (1999) is focused on the forest-based projects and more specifically considers how carbon is inventoried and monitored over the length of project. He takes into consideration the relation between the precision of estimates and the cost to achieve given levels of precision. Remote sensing, as well as models followed by field measurements for verification, are the potential tools for monitoring. To illustrate the inventorying and monitoring methods, the author presents an example of a pilot carbon-offset project.

With regard to monitoring there is also the issue of who is actually undertaking the compliance monitoring. The middlemen are often seen as guarantors of quality of a good or a service (Biglaiser (1993), and Chu and Chu (1994)). They are an information source to consumers and may help to alleviate the producer moral hazard problem (Biglaiser and Friedman 1994). Middleman may be involved in monitoring compliance in the carbon offset market. Moura-Costa and Stuart (1999) describe the steps required for verification of forestry-based carbon offset projects and argue that independent compliance monitoring can add a layer of credibility and transparency to the system. They particularly discuss the importance of standardization of methods and procedures used for monitoring and verification of projects.

The literature also deals with the issues of risk and uncertainty which can affect the expected GHG flows of the project. Diversification of activities within a project, dispersing project sites as well as the establishment of insurance are proposed as ways to deal with risk. A substantial body of literature has developed with reference to insurance and warranties in general (Heal 1997, Lutz and Padmanabhan 1998, Soberman 2003); however the literature regarding insurance in the carbon offset markets is still being established.

Several economists have examined the liability issue. Zhang (1999) considers the assigning of liability as essential for the success of an emission trading scheme. The literature related to this issue tends to focus on seller non-compliance. As different economists argue, the choice for buyer or seller liability depends on a number of factors. Tientenberg et al. (1999) argue that seller liability is preferred if the quality of enforcement is high. High quality enforcement would provide an incentive for the seller that the emission reductions are real, thereby reducing the incentive for cheating. They also argue that under seller liability, buyers are more likely to become active in the market because they do not bear the risk.

Klaassen and Nentjes (2002) argue that the choice of buyer or seller liability depends on the parties' willingness to comply. They show that, compared to a seller liability, a buyer liability improves effectiveness if buyers have a stronger willingness to comply than sellers and if the enforcement system is weak. The advantage of adding buyer liability is that it strengthens compliance incentives by discouraging buyers from purchasing emission reductions from sellers or countries that appear to be heading towards non-compliance. But this would increase the transaction costs by creating price uncertainty until the moment that compliance is checked. Since each option has advantages and disadvantages, some authors have proposed creating hybrid seller/buyer liability arrangements (Zhang 1999, 2001).

The climate change literature expresses a desire for more research on such things as: compliance issues and the consequences of non-compliance on the performance of the carbon-offset market; the way in which monitoring and verification can be done, the extent to which different monitoring agencies undertake monitoring and the impact of this monitoring on the pricing behaviour; the farmers' pooling option while considering different types of aggregators; and the impact of farmers heterogeneity. In this thesis we take steps to address these questions.

CHAPTER IV

THEORETICAL DEVELOPMENT OF THE BASIC MODEL

4.1 INTRODUCTION

This chapter develops a model of heterogeneous farmers to examine the consequences of non-compliance on the performance of the carbon-offset market. The analysis begins with the derivation of the carbon offsets' supply curve in a perfect compliance scenario. The analysis then introduces non-compliance in the economic analysis of the carbon offset market and considers the impact of non-compliance by farmers on the supply of carbon offsets. The chapter examines the economic determinants of farmers' non-compliance and performs some comparative statics analysis.

4.2 MODELING THE FARMERS' PROBLEM[1]

Each farmer cultivates product q under a certain land management practice, which can be either a BMP or a conventional land management practice. As mentioned in Chapter two, BMPs can be of many types such as: reducing tillage, planting permanent cover crops, reducing summerfallow, and planting shelterbelts (Agriculture and Agri-food Canada, 2003a). Each practice gives rise to different rates of carbon accumulation and to different streams of net profits. Due to the economic benefits related to the BMPs many farmers have already adopted these practices. However, a number of farmers still produce under the conventional land management practices because of the new investment required, part of which is sunk, and a lack of experience to undertake change in their practices. In addition to the direct economic benefits, farmers may have an

[1] The thesis will be concentrated on farmers' behaviour, but for the sake of completeness we also present the emitters problem in Appendix 4.

incentive to adopt BMPs in order to participate in the carbon-offset market. However, there are some important considerations for the farmer when he comes to signing the carbon offset contract.

Farmers adopt BMPs to a greater or a lesser degree. They may capture carbon in their soil, but none of this sequestered carbon is available for trading if they don't sign a carbon-offset contract. Farmers are reluctant to sign the contract for such reasons as transaction costs, uncertainty, inflexibility and the risk associated with signing the contract. Examples of transaction costs would be: administrative costs of keeping records and reporting carbon offsets, the costs of undertaking the transaction to sell the carbon offsets, and costs associated with the signing process. These transaction costs can reduce the attractiveness of participating in the carbon-offset market. In a study performed by Marbeck Resource Consultants (2004), the transaction costs for GHG offset system were estimated to range between \$0.4 and \$2 per tonne of CO_2.

Another issue for farmers considering participating in the carbon-offset market is uncertainty. Farmers have to sign the contract under the condition of an uncertain rate of soil carbon accumulation and market price of sequestered carbon. The rate of carbon sequestration can be affected by adverse weather conditions as well as by the market price for the carbon offsets created from carbon sequestration. The carbon price can be affected by changes in demand and supply conditions which are not known at the time of signing. In addition to these aspects, farmers should also take into account that signing the sequestration contract is a highly irreversible decision. Uncertainty, combined with the irreversibility of the decision, implies that delaying the signing decision has an option value. Farmers will enter to a contract relation only if the net present value of their investment exceeds this option value (Vercammen, 2002).

Apart from this, farmers incur additional risk if they decide to sequester carbon under a contract and to sell carbon credits in an emission market. This higher risk might result for a number of different reasons. Eliminating such activities as conventional tillage might generally increase risk. On top of this, adopting BMPs might require investing in a new technology which entails a learning period, a period of a higher risk. Investing in a particular technology might, as well, increase the financial risk. Since farmers are believed to be risk averse, they will require a risk premium in order to participate in a carbon sequestration scheme. The option value, the risk premium, as well as the transaction costs associated with signing the contract constitute the contract costs. Under the above considerations, each farmer will sign the contract only if the benefit from participating in the carbon-offset market exceeds the cost of signing the contract.

Farmers are postulated to differ in the returns they get from their activities as a result of differences in such things as soil type, contract costs, experience, location, education and management skills. The basic model will be a location model that captures the farmers' heterogeneity. For tractability, the farmers are assumed to be uniformly distributed with respect to their differentiating attribute and each farmer is assumed to produce one unit of carbon offsets.

The following analysis will first examine farmers' decision in a full compliance scenario and then will be followed by the analysis of the farmers' choice when non-compliance is introduced in the model. The supply curves will be derived and some comparative statics will be performed for each particular case.

4.2.1 Farmers' Decision on Carbon Offsets Production

Before investigating the farmers' compliance decision, it is helpful to analyze their economic behaviour under a perfect enforcement scenario. This assumption is relaxed with the intention that the more realistic situation, where farmers have the potential to over-report their carbon offsets, be explored.

Farmers have the choice of: (1) signing the carbon sequestration contract; or (2) not signing the contract. Let α denote the attribute that differentiates them. Farmer heterogeneity is critical in generating the supply of carbon offsets.

The per unit profit for a farmer with differentiating attribute $\alpha \in [0,1]$ is given as follows:

$\pi^{nc} = P^q$ if he does not sign the sequestration contract [2]

$\pi^c = P^q + P_e - \lambda\alpha$ if he does sign the sequestration contract

where P_e and P^q are the prices for carbon offset and product q, respectively.

The parameter λ is a non-negative cost enhancement factor that is constant across all farmers. The term $\lambda\alpha$ presents the cost incurred by farmer with $\alpha > 0$. This term embodies the sequestration contract cost which includes the transaction costs associated with signing the contract, the risk premium that farmers require to take on the risk of signing the contract, and the option value that farmers attach to the potential to wait to sign the contract at a latter date (see Weersink et al., 2005, Fulton et. al., 2005). Whether or not a farmer participates in carbon sequestration under a contract depends on the profitability of such involvement. Each farmer makes his choice based on which alternative generates the highest per unit profit.

The horizontal curve π^{nc} drawn in Figure 4.1 represents the net returns associated with the production of product q for different values of α (i.e., for different farmers) where the contract is not signed. The curve π^c shows the net returns associated with signing the contract for different values of the differentiating attribute. The intersection of π^{nc} and π^c determines the level of the differentiating characteristic corresponding to the farmer that is indifferent between signing the sequestration contract and not signing it. This farmer has attribute α^c given by:

(4.1) $\alpha^c : \pi^{nc} = \pi^c \Rightarrow \alpha^c = \dfrac{P_e}{\lambda}$.

[2] More realistically, the farmer's profit would be expressed by: $\pi^{nc} = P^q - \mu\alpha$, where parameter μ would be a non-negative cost enhancement factor that is constant across all farmers. The term $\mu\alpha$ would represent the cost incurred by farmer with $\alpha > 0$. Without loss of generality, it is assumed that $\mu = 0$.

To the left of α^c (i.e., for $\alpha \in \left[0, \alpha^c\right]$) all farmers elect to sign a contract, while to the right of α^c (i.e., for $\alpha \in \left(\alpha^c, 1\right]$) all farmers choose not to sign the contract, no matter what land management practice they are applying. Some of the farmers located between α^c and 1 might be applying BMPs in their land, but they are not entitled to sell the carbon offsets they create as long as they do not sign a sequestration contract. Given that α is uniformly distributed between zero and one, α^c represents the portion of farmers that produce carbon offsets under a contract, while $\alpha^{nc} = \left(1 - \alpha^c\right)$ is the fraction of farmers that do not choose to sign the carbon offset contract. By normalizing the mass of farmers at unity, the fraction of farmers that sign the contract gives the supply of carbon offsets in the market, which is written as follows:

(4.2) $x^c = \dfrac{P_e}{\lambda}$.

The inverse supply function $\left(S_0\right)$ is represented by the equation $P_e = \lambda x^c$.

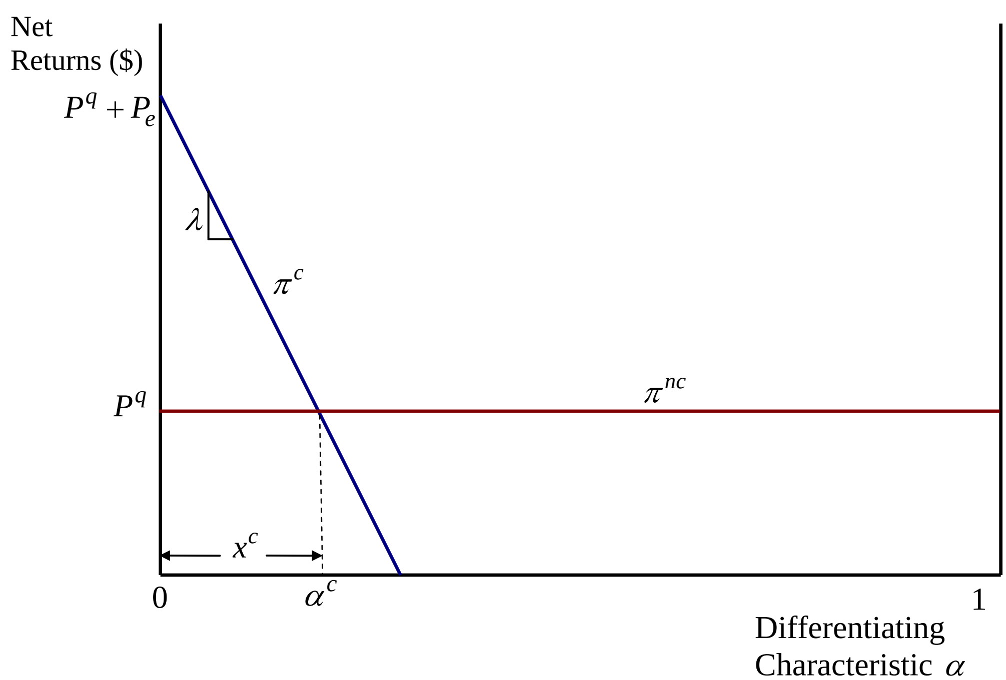


Figure 4.1 Farmers' decision under perfect compliance.

Comparative static results can be obtained from Figure 4.1. The price of carbon offsets is a key factor in determining how many farmers sign the contract. An increase in the price of carbon offsets results in an increase of the benefits from signing the contract, *ceteris paribus*. More specifically, an increase in P_e leads to an upward shift in the π^c line. This upward shift results in a larger portion of farmers signing the sequestration contract (i.e., $\frac{\partial x^c}{\partial P_e} > 0$). Decreasing the cost enhancement factor λ causes a rightward rotation of the π^c curve through the intercept at $P^q + P_e$, thus increasing the number of contracts signed by farmers (i.e., $\frac{\partial x^c}{\partial \lambda} < 0$).

4.2.2 Extending the Basic Model: Introducing Non-Compliance on the Farmers' Side

The previous analysis was performed under the assumption of perfect compliance. But in the real world, the monitoring and enforcement activities required to ensure compliance with a contract are costly. Farmers need to be monitored in order to ensure that the carbon offsets that are claimed represent an actual reduction of carbon. However, the resource costs of monitoring and enforcement might result in insufficient enforcement activity. The lack of enforcement creates economic incentives for farmers to over-report the amount of carbon offsets they are supplying under a contract. Each farmer now has a choice of: (1) signing a carbon offset contract and honouring it; (2) signing the contract but not complying with its terms (i.e., cheating); and (3) not signing the contract.

Suppose farmers are audited with a probability $\theta \in [0,1]$ which is known to them and they face a per unit penalty γ if they are caught cheating on the contract. If a farmer cheats, his expected net return depends on the likelihood of his being audited, the penalty paid if he is caught cheating, as well as his individualized costs. If he does not get detected he can enjoy the benefit $P^q + P_e - \sigma\alpha$, where σ is a cost enhancement factor that is constant across all farmers. The term $\sigma\alpha$ represents the costs incurred by a farmer in the case when he signs the sequestration contract but does not comply with its terms; thus this term embodies the sequestration contract cost as well the costs associated with cheating. Following Cule and Fulton (2005), the cheating cost is associated with activities such as double bookkeeping. The cheating cost moves in the same direction with the sequestration cost since the higher the sequestration cost, the higher the cost of masquerading cheating.

In order to have a range of cheaters, it is assumed that $\lambda > \sigma > 0$; the difference between λ and σ is denoted as $\varphi = \lambda - \sigma$. If the farmer is caught cheating, he gets the benefit $P^q + P_e - \gamma - \sigma\alpha$. As a result, the expected return from cheating for a farmer with characteristic α will be given as follows:

(4.3) $\pi^{ch} = P^q + P_e - \theta\gamma - \sigma\alpha$

Note that, since farmers differ with respect to α, and as a result of their individualized costs $\sigma\alpha$, the expected profits from cheating differ across farmers. The farmer's decision of whether to participate in the carbon-offset market and, if so, whether to comply with the provisions of the sequestration contract depends on the profits received or expected to be received from these alternatives. A graphical illustration of the farmer's decision is given in Figure 4.2. The intersection of curves π^c and π^{ch} determines the level of the differentiating attribute α_1 corresponding to the farmer who signs the carbon offset contract but is indifferent between complying with the terms of the contract and cheating:

(4.4) $\alpha_1 : \pi^c = \pi^{ch} \Rightarrow \alpha_1 = \dfrac{\theta\gamma}{\varphi}.$

In a similar way, the intersection of curves π^{ch} and π^{nc} determines the level of the differentiating attribute α_2 corresponding to the farmer who is indifferent between not participating in the carbon-offset market (i.e., not signing the contract) and signing the sequestration contract but not satisfying its terms:

(4.5) $\alpha_2 : \pi^{ch} = \pi^{nc} \Rightarrow \alpha_2 = \frac{P_e - \theta\gamma}{\sigma}$.

Farmers located to the left of α_1 (i.e., farmers with differentiating attribute $\alpha \in [0, \alpha_1]$) choose to participate in the carbon-offset market; farmers located between α_1 and α_2 (i.e., farmers with characteristic $\alpha \in (\alpha_1, \alpha_2)$) choose to sign the contract but not to comply with all the provisions; and farmers positioned to the right of α_2 (i.e., those with attribute $\alpha \in [\alpha_2, 1]$) choose not to sign the sequestration contract no matter what land management practice they are applying.

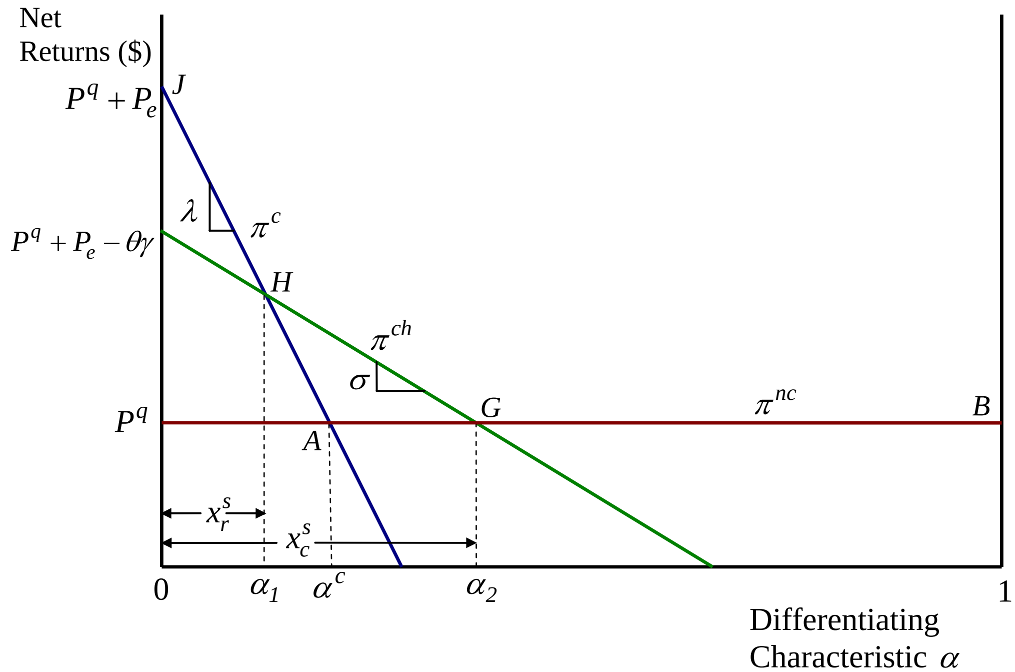


Figure 4.2. Farmers' decision under non-compliance

Since farmers are uniformly distributed with respect to differentiating characteristic α, α_2 determines the portion of farmers that sign the sequestration contract; α_1 gives the portion of farmers who sign the carbon contract and honour its provisions; $(\alpha_2 - \alpha_1)$ gives the portion of farmers that sign the contract but do not comply with its terms; and

$(1-\alpha_2)$ determines the portion of farmers that do not sign the contract. Formally $(\alpha_2-\alpha_1)$ can be written as follows:

$$\alpha_2-\alpha_1=\frac{P_e\varphi-\theta\gamma\lambda}{\sigma\varphi}.$$

The portion of farmers who sign the contract, but do not comply with the provisions, $(\alpha_2-\alpha_1)$, will equal zero when all three curves π^c, π^{ch} and π^{nc} meet at the same point. This happens when the carbon offset price equals $P_e=\frac{\lambda\theta\gamma}{\varphi}$.

By normalizing the mass of farmers at unity, the portion of farmers that choose to sign the contract gives the total supply of carbon offsets in the market, $x_c^s=\alpha_2$, which can be written as follows:

(4.6) $x_c^s=\frac{P_e-\theta\gamma}{\sigma}$.

Having introduced cheating in the model, the supply of total contracts signed by farmers is given by the following equation:

(4.7) $S_2: P_e=\theta\gamma+\sigma x_c^s$.

When cheating is not considered, aggregate farmers' welfare is given by the area $0JAB1$, while, when cheating is introduced into the analysis, the aggregate farmers' welfare is increased by the area HAG.

The carbon offsets offered in the market can come from farmers who actually undertake sequestration or from those who engage in cheating activity. Put in a simple way, carbon offsets supplied in the market can be genuine or bogus. Only farmers positioned to the left of α_1 contribute genuine carbon offsets. As a result, the supply of genuine carbon offsets in the market $x_r^s=\alpha_1$, is given as follows:

(4.8) $x_r^s=\frac{\theta\gamma}{\varphi}$, while the amount of bogus carbon offsets in the market, $x_c^s - x_r^s = \alpha_2 - \alpha_1$, is given by:

(4.9) $x_c^s - x_r^s = \dfrac{P_e\varphi - \theta\gamma\lambda}{\sigma\varphi}$,

The number of farmers that choose not to sign the sequestration contract, $x_{nc}^s = 1 - x_c^s$, is given by:

(4.10) $x_{nc}^s = \dfrac{\sigma - P_e + \theta\gamma}{\sigma}$.

The analysis shows that the number of total contracts signed, the amount of genuine carbon offsets and the amount of bogus carbon offsets offered in the market depends on the audit probability as well as the penalty applied per unit of non-compliance. In addition to these factors, the total number of contracts signed is influenced by the price of carbon offsets and σ; the amount of genuine carbon offsets is impacted by φ; and the amount of bogus carbon offsets is influenced by the price of carbon offsets as well as by the three parameters φ, λ and σ.

This model analyses the farmer's decision when all three choices are available. The relation $P^q + P_e > P^q + P_e - \theta\gamma$ guarantees that a positive number of farmers, $x_r^s > 0$, select to sign the carbon offset contract and to comply with its terms. Assume we have an interior solution so that all three variables x_r^s, x_{nc}^s, and $(x_c^s - x_r^s)$ are positive. This assumption needs the following conditions to hold: in order to have $x_{nc}^s > 0$, $\sigma > P_e - \theta\gamma$ should hold (see equation 4.10); and in order to have $(x_c^s - x_r^s) > 0$, $P_e\varphi > \theta\gamma\lambda$ should hold (see equation 4.9). From equation 4.9, we can derive the critical audit probability value $\theta^{cr} = \dfrac{P_e\varphi}{\gamma\lambda}$ for which full compliance holds (i.e., $(x_c^s - x_r^s) = 0$). For audit probabilities $\theta \geq \theta^{cr}$, non-compliance (i.e., overreporting) will be completely deterred. Each farmer chooses either to sign the carbon offset contract and honour it or to decline the sequestration contract. He does not find overreporting profitable since the probability of being detected is too high.

Figure 4.3 illustrates three supply curves S_0, S_1 and S_2, where: S_0 represents the supply curve under a full-compliance scenario; S_1 represents the supply of genuine carbon offsets; and S_2 represents the total supply of carbon offsets after we have introduced cheating in the model. For prices $P_e < \frac{\lambda\theta\gamma}{\varphi}$ they converge on segment $0T$.

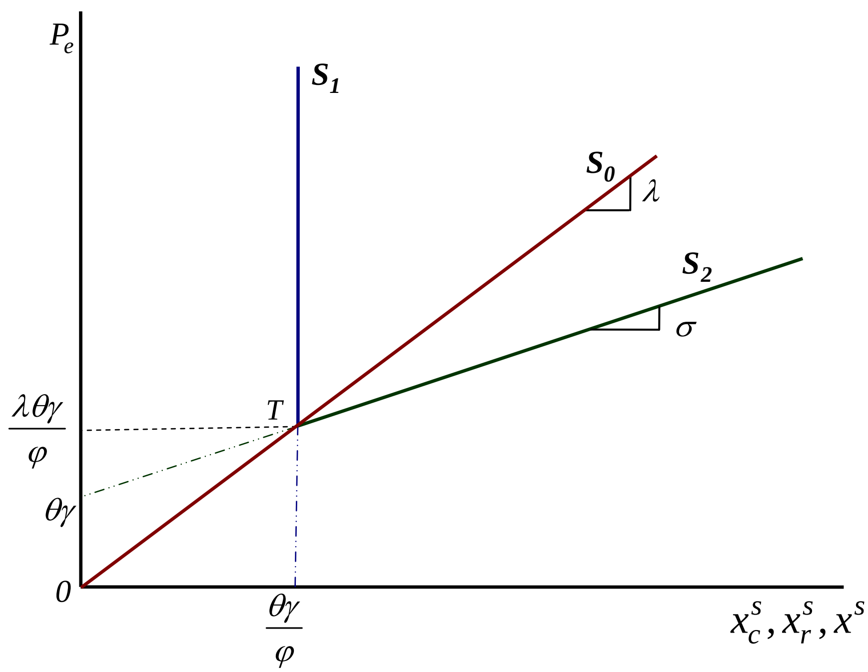


Figure 4.3. Supply curves under both scenarios

4.2.3 Comparative Static Results in the Basic Model

Comparative statics results can be derived diagrammatically from Figure 4.2. An increase in the per unit penalty causes a downward shift in the π^{ch} curve, which in turn results in a decrease in the number of contracts signed as well as in the non-compliance level (i.e., $\frac{\partial x_c^s}{\partial\gamma} < 0, \frac{\partial\left(x_c^s - x_r^s\right)}{\partial\gamma} < 0$), *ceteris paribus*. In a similar way, a higher audit probability causes an increase in the expected penalty and shifts the π^{ch} curve downwards, thus decreasing the amount of bogus carbon offsets as well as the total amount of carbon offsets offered in the market from farmers (i.e., $\frac{\partial x_c^s}{\partial \theta} < 0, \frac{\partial \left(x_c^s - x_r^s \right)}{\partial \theta} < 0$), *ceteris paribus*.

The results from the comparative statics analysis with respect to the auditing probability θ or the penalty variable γ are illustrated in Figure 4.4. The total number of contracts signed by farmers falls from x_T to x_T', the amount of genuine carbon offsets supplied in the market increases from x_r^s to $x_r^{s\prime}$ and the amount of bogus carbon offsets decreases from $\left(\alpha_2 - \alpha_1\right)$ to $\left(\alpha_2' - \alpha_1'\right)$.

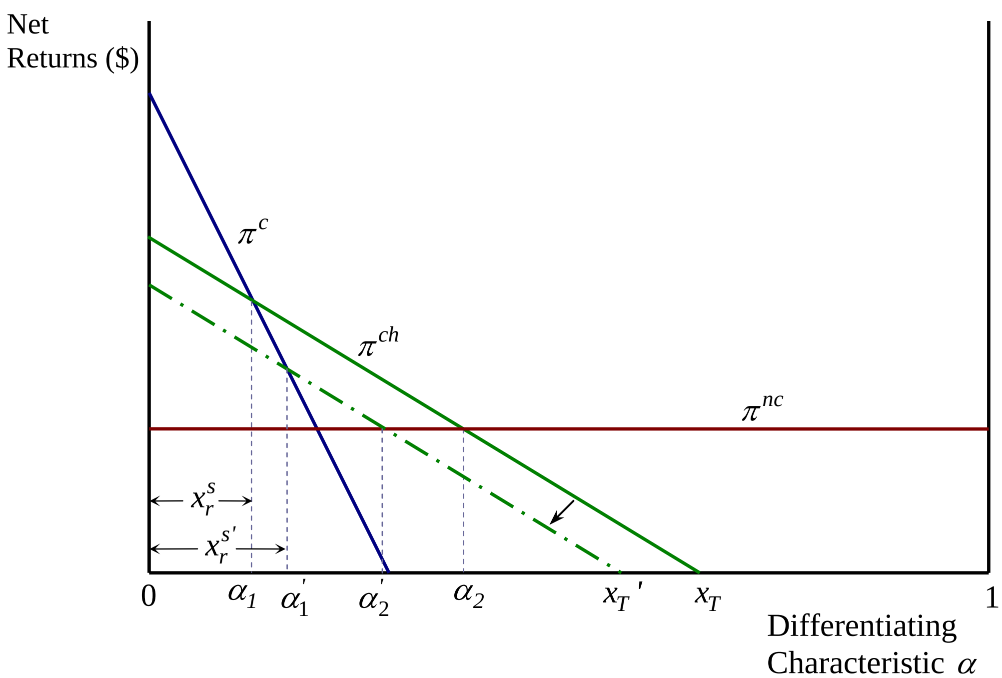


Figure 4.4 Comparative static with respect to the auditing probability θ or the penalty variable γ

An increase in the carbon offset price P_e causes an upward parallel shift of the curves π^c and π^{ch} by the same amount. These shifts result in a higher number of contracts signed (i.e., $\frac{\partial x_c^s}{\partial P_e} > 0$); the amount of carbon sequestered under contract remains constant however.

By examining the supply curves in Figure 4.5 we can draw some implications. An increase in the price of carbon offsets from zero to $\frac{\lambda\theta\gamma}{\varphi}$ increases the number of farmers who sign contracts with full compliance, since nobody who signs a sequestration contract finds it profitable to cheat along section $0T$ of the supply curve.

For a given auditing probability θ, the supply of genuine carbon offsets is fixed at S_1 [3]. An increase in the per unit penalty or in the auditing probability causes a rightward parallel shift in the S_1 as well as an upward shift in the S_2 curve, thus extending the section where the three supply curves converge from $0T$ to $0T'$. As a result, the amount of genuine carbon offsets supplied in the market increases from x_s^r to $x_s^r{}'$.

[3] The vertical supply curve is a result of the linear cost function. A more general case would be where supply S_1 is upward slopping. An earlier version of the model attempted to incorporate a more general cost function, but the analysis become too complicated and the results were not tractable. The assumption of a vertical supply curve, however, does not change the qualitative nature of the results. Note also that in the more general case an increase in price P_e would result in an increase in the number of contracts signed as well as in the amount of genuine carbon offsets supplied.

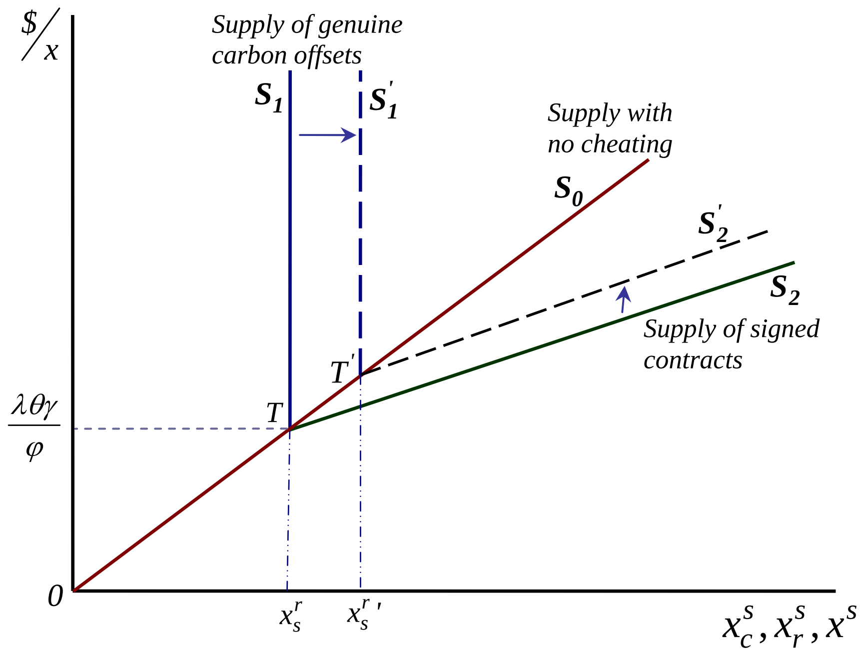


Figure 4.5 The supply curves' shift for a monitoring or a penalty change

4.3 Concluding Remarks

This chapter develops a model of heterogeneous farmers to examine the consequences of non-compliance on the performance of the carbon-offset market. The analysis begins with the derivation of the supply of carbon offsets in a perfect compliance situation. The study then considers the impact of non-compliance by farmers on the supply of carbon offsets.

The analysis suggests that the extent of farmers' participation in the carbon market and the share of farmers in non-compliance depend on the price of carbon offsets and the enforcement policy of the government. More specifically the extent of non-compliance is shown to decrease with an increase in the audit probability and /or an increase in the penalty per unit of non-compliance.

In addition, the number of farmers participating in the carbon-offset market is shown to increase with an increase in the carbon-offset price. The total number of farmers under contract decreases with an increase in the per unit penalty and/or an increase in the audit probability.

CHAPTER V

TRADING AND AUDITING CHOICES UNDER DIFFERENT STRUCTURES FOR THE TRADING SECTOR AND THE MONITORING GROUP

5.1 INTRODUCTION

Carbon offsets trading will be undertaken by traders (or aggregators) that buy carbon offsets from farmers and sell verified carbon offsets to LFEs. This chapter of the thesis considers two organizational structures for the trading sector: the investor owned-firm (IOF) structure and a collectively owned and managed producers' association (PA) structure. Within the IOF, this chapter considers two market structures – monopoly and oligopoly. We expect a monopolistic or oligopolistic structure to emerge because of the fixed costs involved in running a trading scheme.

For each of these cases, we consider monitoring undertaken by a monitoring group which can be either a governmental agency or a monitoring group operating on behalf of the for-profit traders or on behalf of the producers' association trader. Assume the monitoring agents do not cheat.[4] The objective of the governmental agency is assumed to be the efficiency of meeting the environmental targets; thus the targets are assumed to be set by another unit. Even though other structures can be used for the trading sector or the monitoring group, we concentrate the work of this chapter on the ones mentioned.

[4] Monitoring agents will be monitored by Environment Canada. If the third party verifier has confirmed the Greenhouse Gas Assertion, Environmental Canada will then do a final check to confirm that all program requirements have been met. The honesty of enforcers as well as some ways to improve incentives given to enforcers are discussed by Becker and Stigler (1974) in their paper.

The amount of monitoring performed by the monitoring agency defines the total supply of carbon offsets as well as the supply of genuine carbon offsets in the market. This chapter examines the trader's price and output decision as well as the monitoring agency's decision of the choice of θ; the consideration of the last element means the audit probability is endogenized. The optimal amount of enforcement is likely to depend on the nature of the organization that undertakes the enforcement since they might have different objective functions. The chapter examines the extent to which these different monitoring agencies undertake monitoring, and the impact of this monitoring on pricing behaviour.

The supply and the demand equations for the carbon offset market are determined from the farmers' and the LFEs' problem, respectively. LFEs are aware that farmers will be monitored and that carbon offsets traded by third parties will represent actual sequestration[5]. The carbon offsets demand emerging from LFEs will be represented by a demand curve D (see Appendix A4 for the derivation of the demand curve). Given this demand and the supply, the amount of carbon offsets trading and the endogenous auditing probability are determined in a two stage game. In the first stage of the game, the monitoring agency chooses the level of auditing that it will undertake, knowing the farmers' response to this choice of auditing as well as the impact of the chosen θ on the pricing decisions. In the second stage of the game, traders make their decision on how much carbon offsets to buy from farmers and how much to sell to LFEs based on the degree of auditing that has been undertaken. To avoid the non-credible outcomes, the game is solved using backward induction (Kreps, 1990).

[5] This is true if intermediaries trade only the genuine carbon offsets. If emitters would know that only a portion ψ of carbon offsets offered in the market were genuine, the total amount of carbon offsets they would need to buy to meet their requirements would be $1/\psi$ times the emission reduction that is required to be addresses through carbon offset purchases. Since the LFEs will only pay for that portion that is genuine, the aggregator will want to exclude all cheaters since the final emitters will not be prepared to pay full price for any offsets that cannot be deemed genuine.

5.2 PRICING AND TRADING DECISION IN THE MONOPOLY AND OLIGOPOLY CASES

Monopoly case

First we consider the case when the trader is a profit maximizing monopolist-monopsonist. The firm is thus the sole buyer of carbon from farmers and the exclusive provider of verified carbon offsets to LFEs.

Denote by Y the amount of genuine carbon offsets and by X the amount of bogus carbon offsets. The trader buys the amount $(Y+X)$ of carbon of offsets at price P_e and sells only the verified units at price P. The price P_e is given by the linear inverse demand curve $P_e = \eta - \tau Y$.

The profit maximization problem for the trader is:

$$(5.1) \qquad \begin{aligned} &Max_{Y,X}\, PY - P_e(Y+X) \\ &\qquad st \quad Y \le \bar{Y} \end{aligned}$$

where $\bar{Y}$ is defined from the auditing probability $\bar{\theta}$ determined by the monitoring group (i.e., $\bar{Y} = \frac{\bar{\theta}\gamma}{\varphi}$). The solution to this problem is presented in Appendix A5.1. The analysis shows that $X = 0$. This means that, when buying carbon offsets, the monopolist chooses to operate only in the component $0T$ of the farmers' supply curve.

The output for the monopolist is the lesser of Y_m and $\bar{Y}$, where Y_m is determined where $MR_m = MO_m$, and marginal revenue and marginal outlay are derived from the demand curve D and the supply curve S_0, respectively. An explanation for this would be as follows:

If $\bar{Y} < Y_m$, the monopolist would choose $\bar{Y}$ since this is the maximum amount of genuine carbon offsets supplied in the market. After this point he will be buying bogus units and no profit comes from these units. The solution for the trader in this case is:

(5.2) $\bar{Y} = \frac{\theta\gamma}{\varphi}$; $X = 0$; $\kappa = \eta - 2(\tau + \lambda)\frac{\theta\gamma}{\varphi}$

where k is the Lagrangean multiplier from the Kuhn-Tucker conditions (see Appendix A5.1).

If $Y_m < \bar{Y}$, the monopolist would choose Y_m since this output gives him the highest profit. The solution in this case is:

(5.3) $Y_m = \frac{\eta}{2(\tau + \lambda)}$; $X = 0$; κ=0.

With knowledge of the behaviour of the trading firm, the decision of the monitoring group can be considered. If the monitoring group operates on behalf of the firm, it chooses the audit probability θ that maximizes the profit of the firm minus the monitoring cost. Formally, the maximization problem of the monitoring group can be written as:

(5.4) $Max_{\theta}\ P\frac{\theta\gamma}{\varphi} - P_e\frac{\theta\gamma}{\varphi} - \frac{1}{2}\xi\theta^2$

where monitoring cost, $C_m = \frac{1}{2}\xi\theta^2$, is assumed to be an increasing and convex function of the auditing intensity θ, and ξ is a positive scalar that depends on factors such as the total number of farmers and the effort required to perform monitoring.

The problem in equation (5.4) uses the quantity $\bar{Y}$ rather than Y_m. The use of $\bar{Y}$ reflects the knowledge that since the monopolistic trading firm will never trade more than Y_m, the monitoring group will always find it optimal to make $\bar{Y}$ no larger than Y_m. If $\bar{Y}$ were larger than Y_m. then the monitoring group could cut back on monitoring, thus saving the associated costs without affecting the monopolist's output.

In *Y*-space, the first order condition equalizes the marginal revenue with the sum of the marginal outlay and the marginal cost of monitoring $MR_m = MO_m + C_m^{'}$ (see Appendix

A5.1). This condition provides the optimal amount of monitoring which will be given by the formula shown below which is derived in Appendix A5.1:

$$(5.5) \quad \theta^* = \frac{\eta\varphi\gamma}{2(\tau+\lambda)\gamma^2 + \xi\varphi^2}$$

This optimal auditing probability, in turn, defines the position of the genuine carbon offsets supply curve S_1, thus determining the amount of carbon offsets traded by the monopolist in the market, where $\bar{Y}^*$ is given by:

$$(5.6) \quad \bar{Y}^* = \frac{\eta\gamma^2}{2(\tau+\lambda)\gamma^2 + \xi\varphi^2}.$$

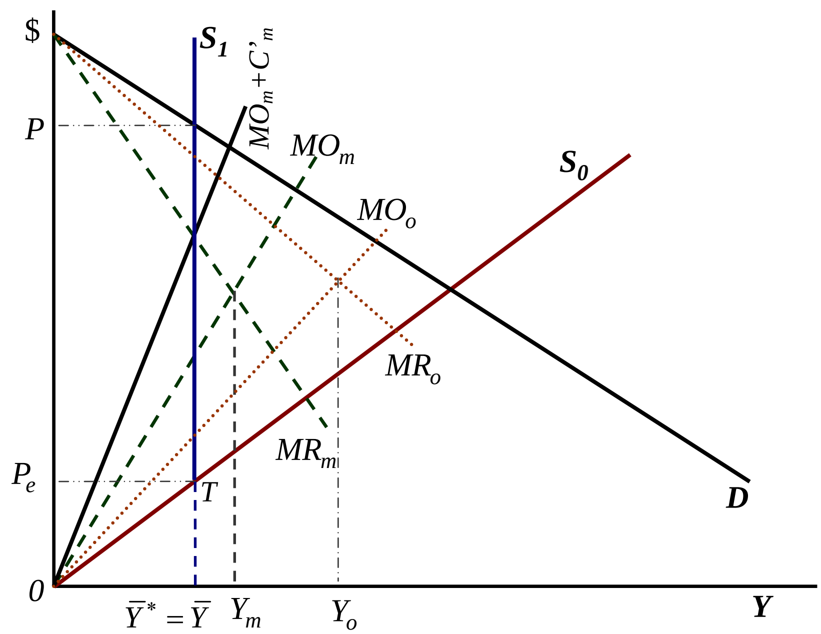


Figure 5.1. Monitoring group decision (monopoly or oligopoly case)

Oligopoly case

Now consider the case when oligopolistic-oligopsonistic firms undertake the carbon offset trading. Representatives from these firms form the monitoring group. The profit maximization problem for each oligopolistic trader is:

$$(5.7) \qquad \underset{y_i, x_i}{Max}\ \pi_i = P(y_i + y_{-i})y_i - P_e\underbrace{(y_i + x_i + y_{-i} + x_{-i})}_{Z}(y_i + x_i)$$

$$st \quad y_i + y_{-i} \leq \bar{Y}$$

where y_i is the output of genuine carbon offsets purchased and x_i is the amount of bogus carbon offsets purchased. The analysis in Appendix A5.2 shows that $x_i = 0$ per each firm, which means that firms trade only genuine carbon offsets.

As with the monopoly, the output will be the lesser of $Y_o : MR_o = MO_o$ and $\bar{Y}$, where MR_o and MO_o are the indusry's marginal revenue and marginal outlay curves in the oligopoly/oligopsony case.[6] The explanation for the above is as follows.

If $\bar{Y} < Y_o$, the choice of the output would be $\bar{Y}$ since this is the maximum amount of genuine carbon offsets supplied in the market. For output greater than $\bar{Y}$, the units are bogus and no profit is derived from these. The total amount of carbon offsets traded in the market in this case is $\bar{Y} = \dfrac{\theta\gamma}{\varphi}$.

If $Y_o < \bar{Y}$, the choice of the output would be Y_o since this output gives the highest profit in the oligopoly/oligopsony case. The total amount of carbon offsets traded would be: $Y_o = \dfrac{\eta N}{(\tau + \lambda)(N + 1)}$ (the formula is derived in Appendix A5.2).

Since traders will never trade more than Y_o, the monitoring group will always find it optimal to make $\bar{Y}$ no larger than Y_o in order to save monitoring costs.

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[6] The marginal revenue curve MR_o in the oligopoly case lies somewhere between the MR_m curve and the demand curve D; the higher the number of emitters, the closer the MR_o curve gets to D.
The marginal outlay curve MO_o lies somewhere between the MO_m curve and the supply curve S_0; the higher the number of farmers participating in the offsets market, the closer the MO_o curve gets to S_0.

From the monitoring group perspective, the group acts on behalf of all oligopolistic firms. The monitoring group thus chooses the audit probability θ that maximizes the profit of all traders minus the monitoring cost. The monitoring group essentially considers all the firms as one firm, whose profit minus monitoring cost should be maximized. Since this objective function is the same as the one corresponding to the monopoly case, the optimal amount of monitoring will be given by equation (5.5) where $MR_m = MO_m + C_m^{'}$. This optimal monitoring probability defines the supply of the genuine carbon offsets, which in this case is the same as in the monopoly case $\overline{Y}^*$. Since $\overline{Y}^*$ is established where $MR_m = MO_m + C_m^{'}$, the monitoring group reduces $\overline{Y}$ to $\overline{Y}^* < Y_o$. Knowing that the output of the oligopoly is the lesser of Y_o and $\overline{Y} = \overline{Y}^*$, the total amount of carbon offsets traded by all firms is given by:

$$(5.8)\quad \overline{Y}^* = \frac{\eta\gamma^2}{2(\tau+\lambda)\gamma^2 + \xi\varphi^2}$$

while the amount of carbon offsets traded by each oligopolistic firm is:

$$(5.9)\quad y_i^* = \frac{\eta\gamma^2}{N\left[2(\tau+\lambda)\gamma^2 + \xi\varphi^2\right]}$$

Both the monopoly and oligopoly scenarios lead to the same solution because of the behaviour of the monitoring group. Even though the traders have the potential to trade more, they do not do so because they are limited in the supply of genuine carbon offsets because of the monitoring activities of the monitoring group.

5.3 Choice of Auditing by a Governmental-Run Agency

This section examines the cases where carbon offsets trading is performed by for-profit firms with monitoring services undertaken by a governmental agency. The analysis considers first the monopolistic structure for the trader followed by the case of an oligopolistic structure.

Monopoly trader/ governmental agency monitoring group

The profit-maximization problem of the monopolist determines $Y_m : MR_m = MO_m$. The monopolistic firm will not trade more than $Y_m = \frac{\eta}{2(\tau + \lambda)}$. A governmental agency chooses the audit probability θ so as to maximize the total welfare, which is the sum of the farmers' surplus, consumer surplus, and trader's profit minus the monitoring costs. Consider first the case where the government maximizes welfare without taking into account the behaviour of the monopoly. The objective function for the governmental agency in this case is:

$$(5.10) \quad W = \pi + CS + PS - C_m = \int_0^{\bar{Y}} [\eta - \tau Y] dY - \int_0^{\bar{Y}} \lambda Y dY - \frac{1}{2}\xi \left(\frac{\bar{Y}\varphi}{\gamma} \right)^2$$

$$= \eta \bar{Y} - \tau \frac{\bar{Y}^2}{2} - \lambda \frac{\bar{Y}^2}{2} - \frac{1}{2}\xi \left(\frac{\bar{Y}\varphi}{\gamma} \right)^2$$

where $\bar{Y} = \frac{\theta\gamma}{\varphi}$. Making this substitution, the maximization problem for the monitoring agency can be written as follows:

$$(5.11) \quad Max_\theta \ W = Max_\theta \ \eta \frac{\theta\gamma}{\varphi} - \tau \frac{(\theta\gamma)^2}{2\varphi^2} - \lambda \frac{(\theta\gamma)^2}{2\varphi^2} - \frac{1}{2}\xi\theta^2$$

The optimal level of the genuine carbon offsets, $\bar{Y}_{uc}^*$, is given by the expression (see Appendix A5.3):

$$(5.12) \quad \bar{Y}_{uc}^* = \frac{\eta\gamma^2}{(\tau + \lambda)\gamma^2 + \xi\varphi^2}$$

This level of output, which is determined by $S_0 + C_m^{'} = D,$ is depicted in Figure 5.2.

However, since the monopoly firm will never trade more than Y_m, the governmental agency will find it optimal to make the output no greater than Y_m in order to save monitoring costs. Thus, monitoring agency reduces the output from $\bar{Y}_{uc}^{*}$ to $\bar{Y}^{g} = Y_m$. The supply S_1 of genuine carbon offsets will be located as illustrated in Figure 5.2. Recall from the previous analysis that the monitoring agency that was operating on behalf of the monopoly undertakes monitoring to position the supply of genuine carbon offsets at $\bar{Y}^{*}$. Even though government agency is constrained in its choice from the monopolist's selection of the trading level, the amount of genuine carbon offsets supplied in this case, $\bar{Y}^{g} = Y_m$, is higher than $\bar{Y}^{*}$. Positioning the supply of genuine carbon offsets at $\bar{Y}^{g}$ requires a higher level of monitoring by the governmental agency. The price received by farmers increases from P_e to P_e' while the price that LFEs are paying for verified carbon offsets decreases from P^m to P^g. The LFEs are better off when the monitoring is undertaken by the governmental agency than by a monitoring agency that operates on behalf of the monopoly because more genuine carbon offsets are supplied in the market and at a lower price. Thus, a governmental monitoring agency has the potential to increase the level of monitoring undertaken and the level of traded output as well as to lower the price paid by LFEs.

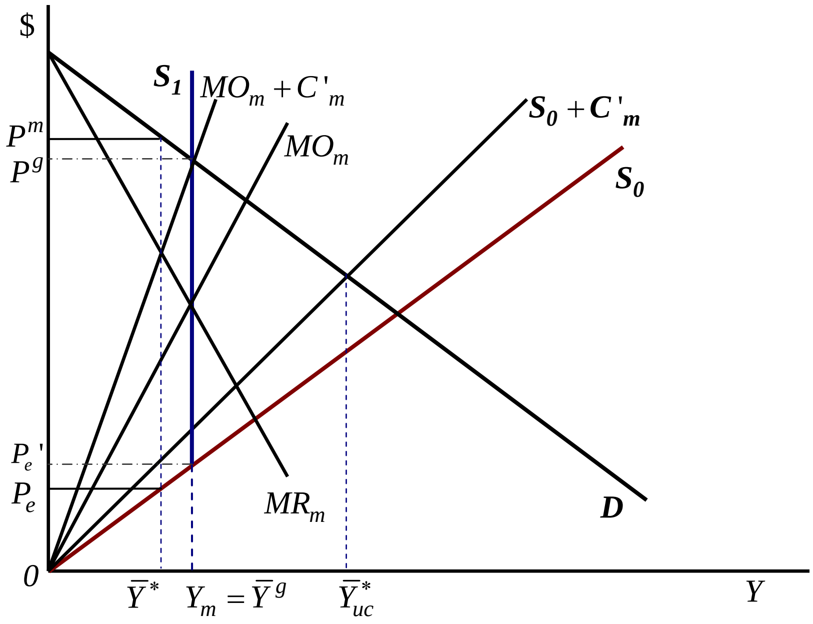

Figure 5.2. Governmental agency monitoring (Case of a monopoly trader)

Oligopoly traders/ governmental agency monitoring group

The total amount of carbon offsets that oligopolistic traders find optimal to trade is determined by equating marginal revenue with the marginal outlay (i.e., $MR_o = MO_o$). Given the supply and demand parameters of our case, this total amount Y_o is given by:

$$(5.13) \quad Y_o = \frac{\eta N}{(\tau + \lambda)(N + 1)} > Y_m$$

Since the oligopolistic firms will never trade more than Y_o, the monitoring agency will find it optimal to make $\bar{Y}^{g'}$ equal to Y_o, otherwise it will waste resources with extra monitoring. The supply of genuine carbon offsets, S_1, will be located as illustrated in Figure 5.3.

From the previous analysis, the monitoring agency that was operating on behalf of the oligopoly chose as optimal the level of monitoring that positions the supply of genuine carbon offsets at $\bar{Y}^*$. In contrast, a government agency selects the optimal audit probability so that $\overline{Y}^{g'}$ of genuine carbon offsets are supplied, where $\overline{Y}^{g'} = Y^o > \overline{Y}^g = Y^m > \overline{Y}^*$. Thus, the amount of monitoring undertaken by the governmental agency in this case is higher than in the previously considered cases. The price received by farmers increases from P^e to $P_e^{"} > P_e^{'} > P_e$, while the price that LFEs are paying decreases from P^o to $P^{g"} < P^{g'}$. In summary, a governmental monitoring agency can potentially increase the level of monitoring undertaken as well as the amount of traded carbon offsets, and lower the price LFEs are paying for the verified carbon offsets.

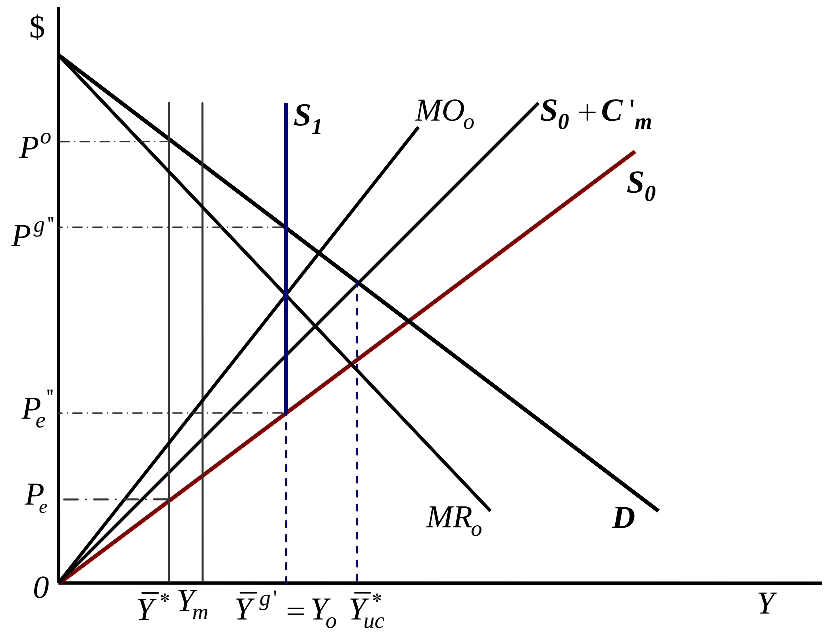

Figure 5.3. Governmental agency monitoring (Case of oligopoly traders)

While there is enough monitoring in each case to deter cheating, the optimal level of auditing probability is different for different structures of the monitoring group. A governmental agency will undertake more monitoring than a monitoring group owned by the firms. The more monitoring is undertaken by the monitoring group, the greater is the amount of genuine carbon offsets in the market; hence the greater is the amount traded by the aggregator/aggregators in the carbon-offset market.

5.4 Producers' Association Case and the Free Rider Problem

The next organizational form considered in this chapter is a producers' association (PA) established to undertake trading of carbon offsets in the market. By forming a PA, the farmers make an investment that can provide benefits to them. The investment would be a monitoring system that would supply monitoring service to the members of the PA. With a PA, farmers produce carbon offsets which are traded through a collectively owned and managed producers association and monitored by a monitoring group that operates on behalf of the PA. Rather than each farmer developing individual contracts, the PA contracts on behalf of the members. Trading carbon offsets through the PA reduces the number of transactions and contracts, thus reducing the time and resources that would be spent otherwise. Forming a PA enables the farmers to benefit from economies of scale as well. The economies of scale may be associated with the fixed costs which will be shared among the members. The PA can handle large volumes so that per unit monitoring costs can be kept low.

Price pooling has an important impact on the PA's ability to market farmers' carbon offsets. Assuming that PA had the necessary information about the costs for each member it would offer different contracts by paying each member the respective cost of sequestering carbon. Given that this information is not available to the PA, the same average price is offered for the product supplied to all the members. Since members are paid the same price per unit of carbon offsets delivered to the pool, each member would prefer to let the others collaborate while he himself defects. In other words, each farmer has the incentive to behave strategically by free riding on the contribution of the others. Farmers who free ride attempt to benefit from price gains created by the pool without sharing in its costs. The result of this strategic behaviour would be to lower the production of genuine carbon offsets, which in turn would reduce the benefits that farmers who do not free ride can obtain from using the PA.

The model of choice most often used to analyze this problem is the Prisoners' Dilemma (PD) in which the dominant strategy is always to free ride (Mueller 1979). Successive work by Axelrod (1984) formalizes the problem as an iterated PD and emphasizes the role of expectations in this process. Runge (1984) illustrates that defection is the dominant choice and some form of coercion is necessary to ensure collective action.

If monitoring was costless, the PA could deal with free riding. But since monitoring the performance of the participants is a costly undertaking, incentives exist for the individuals to shirk on their contribution and free ride on the contribution of the others (Harris et. al., 1998). Under these circumstances, the PA should make its decision about the amount of monitoring to be undertaken and the pooling price it will offer to farmers. The purpose of this section is to examine the manner in which the PA determines the poling price and the probability of auditing and to compare these results to those of the for-profit firms.

5.4.1 Choice of Trading by the Producers' Association

In supplying the verified carbon offsets, the producers' association is concerned with the profitability of the PA as well as the producer surplus, which will be affected by the price P_e paid by the PA to its members per unit of carbon offsets. The PA generates revenue from the sale of verified carbon offsets. The revenue obtained from the sale of these carbon offsets is used to cover the investment costs, the monitoring costs, and the payments to the farmers for the carbon offsets they provided. The cost of the investment is fixed at F, while the monitoring cost $C_m = \frac{1}{2}\xi\theta^2$ is given by the same expression as in the cases considered previously. Out of the total amount of carbon offsets $\hat{Y} = \overline{Y} + X$ claimed by farmers, only $\overline{Y}$ are the units for which the sequestration is actually undertaken. This amount of carbon offsets will be sold in the market at price $P(\overline{Y})$, thus creating revenues $R(\overline{Y}) = P(\overline{Y})\overline{Y}$ for the PA. The fixed costs and the monitoring costs will be covered from the spread between the buying and selling prices. After covering the fixed and the monitoring costs, the PA has to pay farmers for the carbon offsets they provided to the PA. In the case where $R(\overline{Y}) - F - C_m > P_e\hat{Y}$, farmers perceive a dividend payment which attracts them to claim more carbon offsets. They continue to produce until quantity $\hat{Y}$ and price $P_e(\hat{Y})$ are such that all the dividends are exhausted, which is when the following relation holds.

(5.14) $R(\bar{Y}) - F - C_m = P_e\hat{Y}$

The analysis in the monopoly or oligopoly case showed that only genuine carbon offsets will be supplied in the market. Traders will not trade more than the amount $\bar{Y}^*$ which is defined by the supply of genuine carbon offsets S_1. The situation is different in the PA case. Provided that the farmer's break even point is not reached, the PA will supply bogus carbon offsets. The reason is that the PA has to give any profit back to the farmers. This payment will expand the supply of carbon offsets. As a result of the free rider behaviour, part of the offsets supplied will be bogus.

Equation 5.14 represents the behavioural equation for the farmers cooperating under a carbon offsets pool. For a given θ, this equation provides the amount of carbon offsets $\hat{Y}^*$ claimed by farmers which in turn determines the price per unit $P_e^* = P_e(\hat{Y}^*)$ that PA should pay to farmers. This price is obtained by the supply of total carbon offsets S_2 for the value of $\hat{Y}^*$.

$$\frac{R(\bar{Y}) - F - C_m}{\hat{Y}^*} = \theta\gamma + \sigma\hat{Y}^*$$
$$\sigma(\hat{Y}^*)^2 + (\theta\gamma)\hat{Y}^* - \left[R(\bar{Y}) - F - C_m\right] = 0$$

The solving of this quadratic equation in terms of $\hat{Y}^*$ provides the total amount of carbon offsets claimed by farmers as follows:

(5.15) $\hat{Y}^* = \dfrac{-\theta\gamma \pm \sqrt{\theta^2\gamma^2 + 4\sigma\left[R(\bar{Y}) - F - C_m\right]}}{2\sigma}$

We accept only the positive solution $\hat{Y}^* = \frac{-\theta\gamma + \sqrt{\theta^2\gamma^2 + 4\sigma\left[R(\overline{Y}) - F - C_m\right]}}{2\sigma}$. For this amount of carbon offsets claimed, farmers will be paid the price

(5.16) $P_e^* = (\theta\gamma) + \sigma\hat{Y}^* = \frac{\theta\gamma + \sqrt{\theta^2\gamma^2 + 4\sigma\left[R(\overline{Y}) - F - C_m\right]}}{2}$.

This will be a pooled price since the PA offers one contract for all farmers. Both types of carbon offsets offered (genuine and bogus) will be paid at this price as a result of the asymmetric information. Each farmer knows if he is complying or not with the provisions of the contract he has signed, therefore he knows if the carbon offset claimed by him is genuine or bogus, but the PA does not have this information. The PA bases its pricing decision on the auditing probability announced by the monitoring group that operates on behalf of the PA. If $P = P(\overline{Y})$ is the price that LFEs pay for the certified carbon offsets the gross revenues are expressed by the area $PA\overline{Y}O$.

Assuming the fixed cost and the monitoring cost $F + C_m$ are given by area $PABH$, the maximum price that PA can offer to farmers is determined by point H, which is the case when farmers do not cheat (i.e. $\overline{Y} = \hat{Y}$). An increasing volume of bogus carbon offsets claimed by farmers reduces the average price that can be paid to farmers; therefore the curve depicting the pooled price for different volumes will be a downward sloping curve as shown in Fig. 5.4. This pooled price curve corresponds to a given θ and hence a given revenue – thus it can be considered as an isorevenue curve. There is a set of isorevenue curves, each curve corresponding to a different θ.

For a given θ, the PA will buy from farmers the amount $\hat{Y}^*$ of carbon offsets at price P_e^* and will sell the amount $\overline{Y} = \frac{\theta\gamma}{\varphi}$ of genuine carbon offsets to LFEs at price $P(\overline{Y}) = \eta - \tau\overline{Y} = \eta - \tau\frac{\theta\gamma}{\varphi}$.

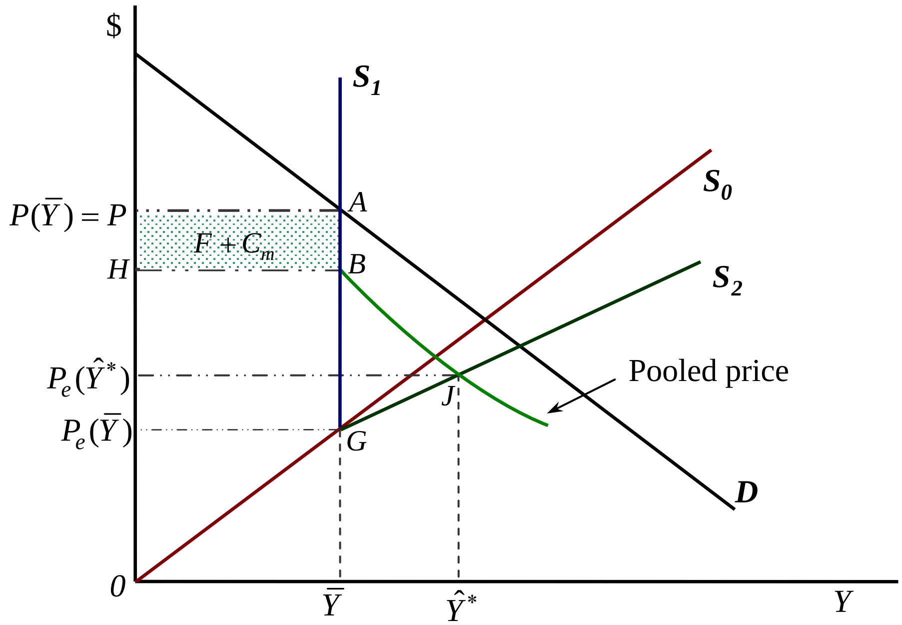

Figure 5.4. Defining the pooled price in a Producers' Association case.

5.4.2 Choice of the Auditing Level and Some Efficiency Considerations

With knowledge of the trading and pricing behaviour of the PA, the decision of the monitoring group can be considered. Since the monitoring group operates on behalf of the PA, it chooses the audit probability θ that maximizes the welfare of the farmers, which is given by producer surplus, subject to the behaviour equation. Producer surplus is given by area $P_e(\hat{Y}^*)JGO$.

The maximization problem for the monitoring group is:

$$Max_\theta \; W = Max_\theta \; PS$$
$$s.t. \quad R(\bar{Y}) - F - C_m = P_e\hat{Y}$$
$$= Max_\theta \; P_e(\hat{Y})\hat{Y} - \int_0^{\bar{Y}} P_0(Y)dY - \int_{\bar{Y}}^{\hat{Y}} P_e(Y)dY$$
$$= Max_\theta \; P(\bar{Y})\bar{Y} - F - C_m - \int_0^{\bar{Y}} P_0(Y)dY - \int_{\bar{Y}}^{\hat{Y}} P_e(Y)dY$$

where $P_0(Y)$ and $P_e(Y)$ are obtained from supply S_0 and S_2, respectively. To take the derivative of the welfare with respect to the auditing probability θ, Leibnitz's Rule[7] is applied for the differentiation of the integrals. The FOC condition for the welfare maximization is as follows:

$$\frac{\partial W}{\partial \theta} = P(\bar{Y})\frac{\partial \bar{Y}}{\partial \theta} + \frac{\partial P(\bar{Y})}{\partial \bar{Y}}\frac{\partial \bar{Y}}{\partial \theta}\bar{Y} - C_m^{'} - \frac{\partial \bar{Y}}{\partial \theta}P_0(\bar{Y}) - \frac{\partial \hat{Y}}{\partial \theta}P_e(\hat{Y}) + \frac{\partial \bar{Y}}{\partial \theta}P_e(\bar{Y}) - \int_{\bar{Y}}^{\hat{Y}} \frac{\partial P_e(Y)}{\partial \theta}dY = 0$$

From figure 5.4 we notice that the two supply curves S_0 and S_2 cross at the carbon offset level $\bar{Y}$; thus $P_0(\bar{Y}) = P_e(\bar{Y})$ and the terms $\frac{\partial \bar{Y}}{\partial \theta}P_0(\bar{Y})$ and $\frac{\partial \bar{Y}}{\partial \theta}P_e(\bar{Y})$ will cancel. From the first order condition we thus obtain the following condition:

$$(5.17) \quad MR\frac{\partial \bar{Y}}{\partial \theta} - C_m^{'} - P_e(\hat{Y})\frac{\partial \hat{Y}}{\partial \theta} - \int_{\bar{Y}}^{\hat{Y}} \frac{\partial P_e(Y)}{\partial \theta}dY = 0$$

The derivative of $\hat{Y}$ with respect to the monitoring probability θ can be obtained by totally differentiating the behavioural equation (5.14):

$$\left(MR\frac{\partial \bar{Y}}{\partial \theta} - C_m^{'} - \frac{\partial P_e(\hat{Y})}{\partial \theta}\hat{Y} \right) d\theta + MO_2 d\hat{Y} = 0$$

$$\frac{\partial \hat{Y}}{\partial \theta} = \frac{MR\frac{\partial \bar{Y}}{\partial \theta} - C_m^{'} - \frac{\partial P_e(\hat{Y})}{\partial \theta}\hat{Y}}{MO_2}$$

From the supply equation S_2, $P_e = \theta\gamma + \sigma\hat{Y}$ and thus $\frac{\partial P_e(\hat{Y})}{\partial \theta} = \gamma$. Substituting these two findings in equation (5.17) and making the following transformations results in condition (5.18):

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[7] If $z = \int_{h(x)}^{g(x)} f(x,y)dy$ then $\frac{\partial z}{\partial x} = \frac{\partial g(x)}{\partial x} f(x,y)\big|_{g(x)} - \frac{\partial h(x)}{\partial x} f(x,y)\big|_{h(x)} + \int_{h(x)}^{g(x)} \frac{\partial f(x,y)}{\partial x}dy$

$$\left(MR\frac{\partial \overline{Y}}{\partial \theta} - C_m^{'} \right) - \frac{P_e(\hat{Y})}{MO_2}\left(MR\frac{\partial \overline{Y}}{\partial \theta} - C_m^{'} \right) + \frac{P_e(\hat{Y})}{MO_2}\frac{\partial P_e(\hat{Y})}{\partial \theta}\hat{Y} - \gamma Y \Big|_{\overline{Y}}^{\hat{Y}} = 0$$

$$\left(MR\frac{\partial \overline{Y}}{\partial \theta} - C_m^{'} \right)\left(1 - \frac{P_e(\hat{Y})}{MO_2} \right) + \frac{P_e(\hat{Y})}{MO_2}\gamma\hat{Y} - \gamma(\hat{Y} - \overline{Y}) = 0$$

$$\left(MR\frac{\partial \overline{Y}}{\partial \theta} - C_m^{'} \right)\left(1 - \frac{P_e(\hat{Y})}{MO_2} \right) = \gamma\hat{Y}\left(1 - \frac{P_e(\hat{Y})}{MO_2} \right) - \gamma\overline{Y}$$

$$\left(MR\frac{\partial \overline{Y}}{\partial \theta} - C_m^{'} \right) = \gamma\left(\hat{Y} - \overline{Y} - \hat{Y}\frac{P_e}{MO_2} \right)\frac{MO_2}{\hat{Y}\frac{\partial P_e}{\partial \hat{Y}}}$$

(5.18) $$\left(MR\frac{\partial \overline{Y}}{\partial \theta} - C_m^{'} \right) = \gamma\frac{MO_2\left(\hat{Y} - \overline{Y} \right) - Pe\hat{Y}}{\hat{Y}\frac{\partial P_e}{\partial \hat{Y}}}$$

Recalling the equivalent condition from the for-profit firms' case we have:

(5.18') $$\left(MR\frac{\partial \overline{Y}}{\partial \theta} - C_m^{'} \right) = MO_0\frac{\partial \overline{Y}}{\partial \theta}$$

Since it is impossible to analytically compare (5.18) with (5.18'), a set of numerical simulations are undertaken to determine the conditions under which PA undertakes more monitoring than the FPF. The starting values for the exogenous variables in the simulation are as follows: the intercept η of the demand curve equals 10; the slope τ of the demand curve equals 1.2; the slope of the supply curve under a full compliance scenario is given by $\lambda = 1.2 < \sigma = 0.3$, where σ is the slope of the supply curve S_2; the penalty γ equals 0.2, the positive scalar ξ equals 0.6, and the fixed costs F equal 0.5. With these values, the optimal value of θ is the same for both the FPF and the PA case ($\theta_{PA} = \theta_{FPA} = 1.94$) – i.e., both (5.18) and (5.18') hold.

For each exogenous variable, values above and below the starting values were chosen and the corresponding optimal monitoring levels θ_{PA} and θ_{FPF} were calculated. Although extensive simulations were performed, only a portion of the many simulations that were carried out is presented in Table 5.1. The relationships presented hold over a wide variety of values of the exogenous variables being examined. The base solution is highlighted in the table for each simulation performed for a particular exogenous variable. The last two columns in the table show the values of the arc elasticity of θ with respect to each of the exogenous variables. The arc elasticity is defined as the ratio of the percentage change in θ (*ceteris paribus*) to the percentage change in the selected exogenous variable.

The simulation results show that the larger are γ, σ, and F, or the smaller are η and ξ, the larger is the monitoring level for the PA relative to the FPF. The monitoring level defines the position of the supply S_1 and, as a result, the amount of the genuine carbon offsets traded in the market. Since the level of the real carbon offsets increases proportionally with θ, the PA will supply more genuine carbon offsets in the market when the parameters γ, σ, and F are relatively large and when the parameters η and ξ are relatively small. Under these conditions, farmers sequester more carbon in their soil when the monitoring of carbon offsets is performed via a PA than by for-profit firms and they are paid a higher price for their product (Figure 5.5). The LEFs are also better off since they pay a lower price for the genuine carbon offsets.

Table 5.1. Optimal θ in the PA and FPF cases. Numerical simulation results for different values of the exogenous variables

Exogenous variables ↓	Changing variable ↓	Optimal θ		Arc Elasticity	
		FPF	PA	FPF	PA
$\sigma = 0.30$ $\lambda = 1.20$ $\xi = 0.60$ $\eta = 10.00$ $\tau = 1.20$ $F = 0.50$	$\gamma = 0.110$	1.81958535	1.81243705	0.76913350	0.80609354
	$\gamma = 0.115$	1.88359904	1.87822761	0.76005585	0.81023092
	$\gamma = 0.120$	1.94552529	1.94412438		
	$\gamma = 0.125$	2.00534759	2.00924186	0.74188916	0.80705949
	$\gamma = 0.130$	2.06305543	2.07431962	0.73280995	0.80983663
$\gamma = 0.120$ $\lambda = 1.20$ $\xi = 0.60$ $\eta = 10.00$ $\tau = 1.20$ $F = 0.50$	$\sigma = 0.20$	1.79340028	1.75192442	0.20080296	0.25673437
	$\sigma = 0.25$	1.86695489	1.84369957	0.22610220	0.29090085
	$\sigma = 0.30$	1.94552529	1.94412438		
	$\sigma = 0.35$	2.02936612	2.05394948	0.27370281	0.35648775
	$\sigma = 0.40$	2.11864406	2.17467123	0.29631418	0.38954741
$\gamma = 0.120$ $\sigma = 0.30$ $\xi = 0.60$ $\eta = 10.00$ $\tau = 1.20$ $F = 0.50$	$\lambda = 1.00$	2.3505708	2.39296724	-1.03732221	-1.13931910
	$\lambda = 1.10$	2.13219616	2.14419638	-1.0529714	-1.12575104
	$\lambda = 1.20$	1.94552529	1.94412438		
	$\lambda = 1.30$	1.78571428	1.78238231	-1.07084731	-1.08518121
	$\lambda = 1.40$	1.64818699	1.64964405	-1.07593506	-1.06552983
$\gamma = 0.120$ $\sigma = 0.30$ $\lambda = 1.20$ $\eta = 10.00$ $\tau = 1.20$ $F = 0.50$	$\xi = 0.40$	2.74725274	2.80716187	-0.85104585	-0.90602684
	$\xi = 0.50$	2.27790432	2.29291693	-0.86508614	-0.90506624
	$\xi = 0.60$	1.94552529	1.94412438		
	$\xi = 0.70$	1.69779286	1.69115596	-0.88357001	-0.90430604
	$\xi = 0.80$	1.506024096	1.499806185	-0.89007591	-0.90217206
$\gamma = 0.120$ $\sigma = 0.30$ $\lambda = 1.20$ $\xi = 0.60$ $\tau = 1.20$ $F = 0.50$	$\eta = 9.00$	1.75097276	1.77328987	0.99999999	0.87295683
	$\eta = 9.50$	1.84824902	1.85749515	0.99999999	0.88866976
	$\eta = 10.00$	1.94552529	1.94412438		
	$\eta = 10.50$	2.04280155	2.03091312	1.00000000	0.89513566
	$\eta = 11.00$	2.13937315	2.11819124	0.99654468	0.89970291
$\gamma = 0.120$ $\sigma = 0.30$ $\lambda = 1.20$ $\xi = 0.60$ $\eta = 10.00$ $F = 0.50$	$\tau = 1.00$	1.96592398	1.96523717	-0.05720849	-0.05924285
	$\tau = 1.10$	1.95567144	1.95462620	-0.05978036	-0.06191474
	$\tau = 1.20$	1.94552529	1.94412438		
	$\tau = 1.30$	1.93548387	1.93378959	-0.06464868	-0.06659061
	$\tau = 1.40$	1.92554557	1.92356322	-0.06696481	-0.06897393
$\gamma = 0.120$ $\sigma = 0.30$ $\lambda = 1.20$ $\xi = 0.60$ $\eta = 10.00$ $\tau = 1.20$	$F = 0.30$	1.94552529	1.90345597	0.000000000	0.04138500
	$F = 0.40$	1.94552529	1.92318232	0.000000000	0.04853564
	$F = 0.50$	1.94552529	1.94412438		
	$F = 0.60$	1.94552529	1.96498054	0.000000000	0.05852656
	$F = 0.70$	1.94552529	1.99126091	0.000000000	0.07119867

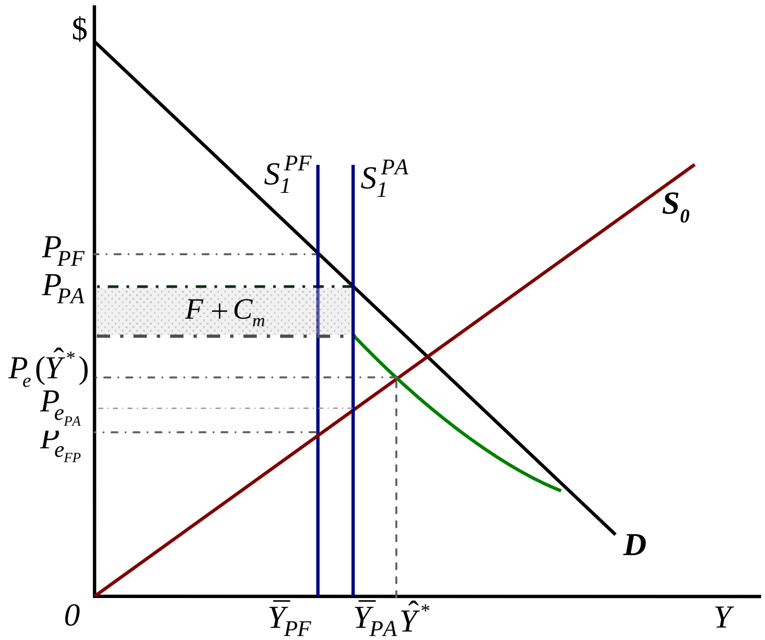


Figure 5.5. Comparing prices and supplies of genuine carbon offset in case of monitoring undertaken by for-profit firms or PA

5.5 Concluding Remarks

This chapter examines what impact the involvement of traders in the carbon-offset market has on non-compliance, as well as how the structure of the monitoring group affects non-compliance, the amount of carbon offsets traded in the market as well as pricing.

Based on the supply and demand curves, the analysis considers the price and the quantity traded that are established by intermediaries that are engaged in carbon offset trading. The key role of the traders is to guarantee, based on the amount of monitoring that is undertaken, that the LFEs purchase only carbon offsets that correspond to actual sequestration. Two organizational structures are considered for the trading sector: the IOF (investor owned-firm) structure and the PA (producers' association) structure. Within the IOF, the analysis focuses on the monopoly and oligopoly structures.

The analysis then examines three cases for the group that monitors farmer compliance – a group owned by for-profit traders, a government-run agency and a group owned by the PA trader. The results of the analysis show that both for-profit firms and the governmental agency undertake sufficient monitoring to ensure that full compliance is achieved – thus, while non-compliance is possible, it does not occur in equilibrium. Since the level of monitoring effectively determines the amount of carbon that is sequestered and that can be traded, a monitoring group owned by for-profit traders can achieve monopoly profits for the sector, even when it is oligopolistic.

A governmental agency would undertake more monitoring than a monitoring group owned by for-profit firms. This would result in more trading activity as well as more genuine carbon offsets supplied in the market. Emitters would be paying a lower price for carbon offsets and farmers would be paid a higher price per unit of carbon offset supplied in the market. However, all these changes are likely to be small, particularly when the trading sector is monopolistic.

The analysis also shows that under certain conditions, the PA undertakes more monitoring and supplies more genuine carbon offsets in the market than does a for-profit trading company. Farmers sequester more carbon in their soil and are being paid a higher price for their product when the monitoring and trading of carbon offsets is performed via the PA itself than by for-profit firms. The LFEs on the other side pay a lower price for carbon offsets when the units are supplied by a PA than by for-profit firms. Thus, from society's perspective, it is more efficient that trading and monitoring in the carbon offset market be undertaken by a PA.

The analysis in this chapter shows that the optimal amount of enforcement, and as a result the cost effectiveness of a carbon-offset market, depends on the nature of the organization that undertakes the enforcement.

CHAPTER VI

CAPTURING THE HETEROGENEITY ATTRIBUTED TO THE SEQUESTRATION PHASE   COMPARING ALTERNATIVES WHEN CARBON OFFSETS ARE AGGREGATED IN A POOL

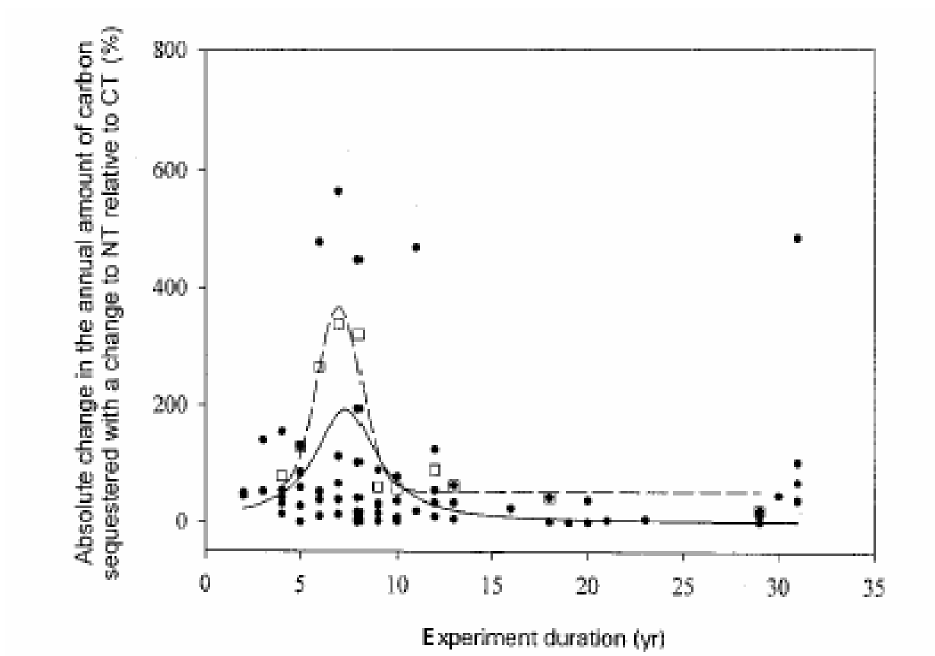
6.1 INTRODUCTION

The type of farmers' heterogeneity captured in Chapters IV and V was attributed to the cost differences among different farmers. For simplicity we assumed that each farmer produced one unit of carbon offsets, which means that, along this dimension, the farmers were identical. This assumption will be relaxed for the work presented in this chapter. More specifically, this chapter focuses on another category of heterogeneity, namely the magnitude of sequestration that farmers can undertake.

Changes in land management practices can substantially improve (or worsen) the accumulation rate of carbon in the soil. However, in accumulating carbon, terrestrial sinks are limited by the ecosystem capability in interaction with the land management system (Lee., H.C. et al., 2003). Sequestration accumulates carbon until the absorptive capacity is used and a new equilibrium is reached under the management system. West and Post (2002) examined 67 long-term tillage experiments[8] and found that, with a change from conventional tillage (CT) to no tillage (NT), "the carbon sequestration rates … can be expected to peak in 5 to 10 years … reaching a new equilibrium in 15 to 20 years" (page 1930) (see figure 6.1). This means that over time the rate of soil carbon

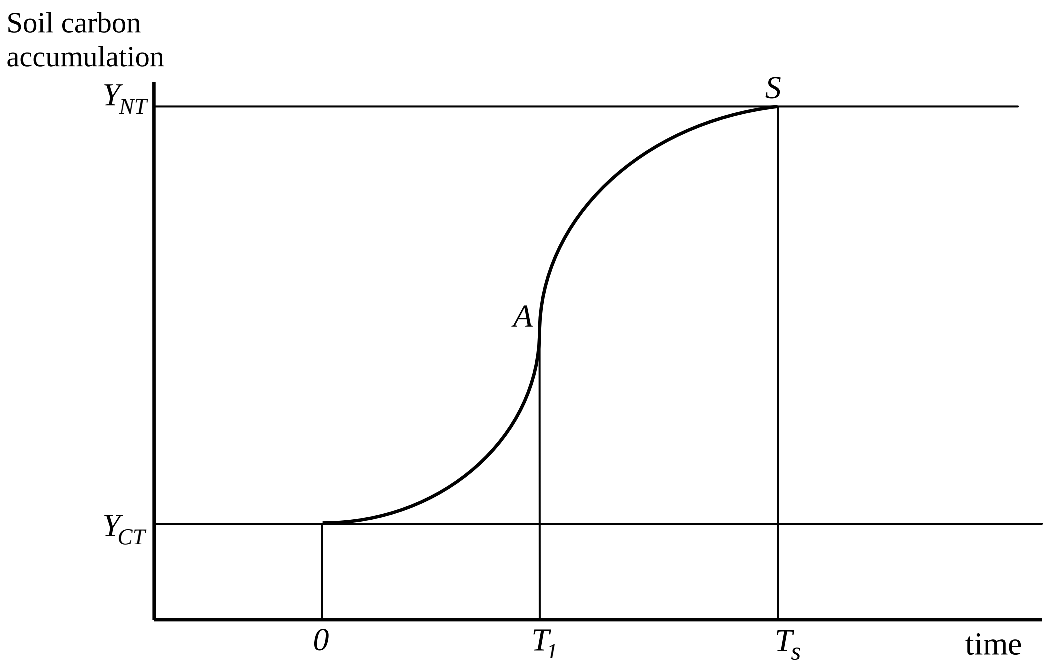
[8] This study was conducted by using a global data base of 67 long-term agricultural experiments from the published literature that recorded the response of SOC (soil organic carbon) to changes in tillage and that were greater than 5 yr in duration.

accumulation increases until it reaches a peak and then decreases over time until the soil becomes saturated.



Source: West and Post (2002). *Solid line represents data using a nonlinear regression.*
Figure 6.1. The percentage change in annual soil organic C sequestration rates under NT, relative to CT

Farmers store different amounts of carbon in their soil depending on which phase of sequestration they are experiencing. Figure 6.2 shows the time path of carbon sequestration in the soil in response to a change in the management practice. Under the existing land management practice (say conventional tillage), the accumulated soil carbon is Y_{CT} at time $t = 0$. After the farmer switches his land to a new land management practice (say no-tillage), the soil starts to absorb more carbon. The rate of absorption increases until it reaches the peak at time $t = T_1$ and starts to decrease after that until the sequestration ceases at the saturation point S. The maximum amount of carbon that can be stored in the land under that particular management regime is Y_{NT} and a new steady-state is reached. There would be no additional net change in the soil carbon if land use and land management practice remain the same.



Source: Adopted from Antle and McCarl (2001).

Figure 6.2. Soil carbon accumulation in response to a change in the land management practice

As a result of this carbon sequestration time path, farmers may sequester different quantities of carbon at the same point in time for the same land size depending on which sequestration phase they are. This is the type of heterogeneity that the model of this chapter will capture. A farmer that just started to apply the no tillage practice will not accumulate the same soil carbon as a farmer that has been using this practice for 5 years or as a farmer that has been using no tillage for 15 years.

Farmers continue to switch from conventional tillage to no-till or low till techniques. Boame (2005) points out in his paper that the no-till area increased from 29.7% of the area tilled in 2001 to 46.4% in 2006. Thus farmers will form a heterogeneous population based on previous rates of adoption of low tillage or no tillage. By the time a carbon trading system is set up, some farmers might be very close or have already reached the saturation point in their land. At this point, a question might be raised regarding the farmers' incentive to release their carbon stock and start over. But those farmers have adopted no tillage techniques because of other economic benefits related to soil organic matter. If farmers release the carbon stock back to the atmosphere they will lose all the benefits they created over the years. In short, the opportunity cost of getting rid of the stock can be quite high (and likely increases over time), which in turn reduces the incentive for farmers to release their carbon back and start over.

As was discussed in chapter V, farmers might consider joining an offsets pool. The pool would be an organized group who agree under a contract to apply a specified set of BMPs to produce credits in aggregate (Marbeck Resource Consultants. 2004). The pool will undertake the monitoring as well as the trading of carbon offsets. This chapter considers the case of a pool owned and managed by the farmers and compares this to the case of an aggregator who runs the business on a for-profit basis. These two structures are the ones examined because they are the organizational forms emerging in the carbon-offset market. The objective functions for these two cases, as well as the accessible information sets, are different. In addition, in the for-profit aggregator case, the aggregator chooses the farmers' type while in the producers' association case, the farmers choose the type of pool they will form.

There are several advantages associated with offsets pooling. One advantage of pooling option would be the risk reduction. The amount of carbon sequestered in the soil depends in part on weather conditions, with less carbon being sequestered in a dry year. By pooling the carbon produced by a large number of farmers, particularly if they are located over a wide geographic area, an aggregator – whether operated on a for-profit or break-even basis – can reduce the risk of weather fluctuations.

A second advantage of aggregating the offsets from different farmers is the ability to capture the economies of scale present in supplying carbon credits. By aggregating carbon offsets, the aggregator is able to spread the fixed costs associated with the provisions of carbon credits over a larger volume, thus lowering average costs. The fixed costs include such things as administrative costs, the developing of monitoring and inventory systems, and the cost of establishing a marketing effort.

Since different farmers supply different amounts of carbon to the pool, the aggregator may decide to vary the payment to different producers based on the quantity supplied. The pricing strategy used in this chapter is a two-part tariff which comprises a fixed fee plus a uniform price per each unit purchased. Based on the timing of sequestration, farmers can be categorized as being in an early stage, a medium stage or the late stage of sequestration. The information that PA would need to classify farmers in these categories is relatively easy to obtain, so pricing based on quantity is possible.

The rest of the chapter is organized as follows. Section 6.2 describes the framework developed to examine the monitoring and pricing decision for the pool. Subsection 6.2.1 explores the default coefficient case while the next subsection delves into the custom coefficients' case. Both subsections look at two different types of aggregators – a for-profit aggregator (FPA) and a producers' association (PA). The chapter considers both a heterogeneous pool and a homogeneous pool in order to answer the question: what is the likelihood that a for-profit structure or a break-even structure of the pool will lead to a homogeneous or a heterogeneous pool? The chapter also compares the alternatives of custom coefficients versus default coefficient for each aggregator type. The last section concludes the chapter.

6.2 The Model

This model assumes a fixed number N of farmers with carbon sequestering potential who are considering participation in the carbon offset market by joining in a pool. As mentioned in chapter IV, some farmers may have already adopted beneficial land management practices, others are in the process of switching their land management practices to BMP and another fraction of farmers is considering the change in the near future. Thus, they are sequestering different amounts of carbon based on the sequestration phase in which they are. Assume the size of the land on which each farmer is considering to apply BMP under a contract is the same. We categorize farmers in two broad groups. One group includes the farmers who are in the early stage or the late stage of sequestration and sequester relatively small amounts of carbon in their soil, while the other group contains those farmers that are in the middle stage of sequestration and sequester large amounts of soil carbon[9]. We use the index s to identify the first group and the index l to identify the second group, thus $i \in \{s;l\}$.

The situation will be modeled as a principal-agent problem[10] where the principal (also referred to as the aggregator) can be either a for-profit firm or a producers' association while the agents are the farmers. The principal undertakes monitoring as well as the trading of carbon offsets in the market. The pricing schedule used by the aggregator is a two-part tariff. A two part tariff is administratively simple and is the simplest form of a more general nonlinear tariff. The two-part tariff is used as a way of providing an incentive for the farmers sequestering large amounts of carbon to participate in the pool. Under the two-part tariff, each farmer pays a lump sum fee of M (if M is negative, the farmer receives a payment from the aggregator to sign a carbon contract) to the principal for the service offered and receives back a payment of P_e for each unit of carbon offsets supplied. The monitoring undertaken by the aggregator ensures emitters that they are buying genuine carbon offsets. The price emitters pay for the certified carbon offsets is determined in the carbon offset market and is assumed to be constant at P^*. This assumption is consistent with a situation where the aggregator covers a specific geographical area in buying and monitoring carbon offsets but sells the certified product in a larger market in which the aggregator is a price taker. The revenues

[9] This analysis categorizes farmers by the stage of sequestration with large sequesters and small sequesters. Another categorization would be by the stock of CO_2 already sequestered: low, medium, and high stocks. This categorization would further differentiate the small sequesters group since some will have a large stock of CO_2 in the soil and some a small stock. The risk of releasing the stocks back in the atmosphere is higher for the large stock group.
We will continue our analysis based on the previous categorization (small sequesters and large sequesters) – thus, the farmers in the early stage of sequestration and in the late stage of sequestration are grouped together. This approach is predicated on the assumption that farmers with large stocks will not intentionally release their CO_2 stock back in the atmosphere. The justification for this assumption is that, by releasing their stock back in the atmosphere, faremrs lose all the benefits associated to the soil carbon matter accumulated through the years.

[10] The same approach is used by Choe and Fraser (1999), and Latacz-Lohmann (1998) in their work.

available for covering the monitoring expenses can be collected from either the lump sum fee or from the difference $\left(P^* - P_e\right)$. Regarding the objective functions, the FPA chooses M and P_e in order to maximize profit, while the PA maximizes members' welfare by breaking even. Note that the lump sum fee may be negative, implying that the aggregator pays the producer a lump sum to participate; in this case the revenue obtained from selling the carbon credits must be large enough to cover both M and the per unit payment P_e.

The aggregator uses sequestration coefficients to determine the amount of carbon offsets for which each farmer is eligible for payment. This model considers two types of coefficients that could be used: default coefficients and custom coefficients. Under the default coefficient case, the aggregator uses the same coefficient for all farmers when deciding the amount of carbon offsets for which the farmer will be entitled to receive payment. This means that all the farmers will receive the same payment regardless of the sequestration stage in which they are in. Since the aggregator doesn't need specific information about the sequestration stage for the farmers, the cost of administering the pool may be lower.

Under the custom coefficients case, the coefficients used will be linked to the stage of sequestration; thus farmers from different stages of sequestration will get payments for different amounts of carbon offsets. In order to do this, the aggregator needs information about the stage of sequestration a farmer is in. A farmer who is in the early or late stage of sequestration produces x_s of carbon offsets which is smaller than the amount x_l of carbon offsets that a farmer in the middle stage of sequestration produces. The aggregator not only needs specific information about the sequestration stage for each farmer, but also needs to monitor the sequestration stage through time. As a result, the aggregator incurs higher information and monitoring costs in the custom coefficients case than in the default coefficient case.

The following sections will deal first with the default coefficient case which will be followed by the custom coefficients case.

6.2.1 Default Coefficient Case

This section deals with the default coefficient case. As mentioned in chapter II, a farmer might have an incentive to adopt a BMP due to the direct economic benefits related to this practice as well as the potential benefits from participating in the carbon offset market. The farmer will be eligible to get the benefits of trading the carbon offsets only if he signs the sequestration contract. In the default coefficient case, the aggregator introduces a sequestration contract that farmers may choose to sign. The farmer who signs the contract agrees to apply a certain BMP to his land and to supply the carbon offsets to the aggregator for trading. The same default coefficient will be used for all the farmers involved in the pool; thus the same amount of carbon offsets, x_d, will be associated with a payment for each pool's member regardless of the sequestration phase that he is experiencing. The aggregator pays each contract signer the price P_e for the default quantity x_d.

A farmer produces a product q under a certain land management practice, which can be either a BMP or a conventional land management practice. He gets the revenue R from this production activity. If the farmer does not sign the carbon sequestration contract, his profit π_i^0 is:

(6.1) $\pi_i^o = R - C^o\left(x_i\right)$

where $C^o\left(x_i\right)$ stands for the costs faced by the farmer.

The profit $\pi_i^{h_d}$ of a farmer from group i who signs the contract with the pool and honours it is given by:

(6.2) $\pi_i^{h_d} = R + P_e x_d - C^{h_d}\left(x_i\right) - M$.

The term $C^{h_d}\left(x_i\right)$ represents the cost incurred to the farmer when the contract is honoured and includes the transaction cost of signing the contract and the sequestration cost. The farmer does not need to keep records and report the amount of carbon sequestered since he is paid only for the given default quantity x_d no matter how much sequestration he undertakes. Hence, the term $C^{h_d}\left(x_i\right)$ does not include any reporting or record-keeping cost.

Each farmer signs the sequestration contract with the aggregator only if he can obtain a profit after signing which is at least as large as the profit before signing the contract. Farmers participate in the carbon market if the following individual rationality constraint is satisfied:

$$IR_i^d: \quad \pi_i^{h_d} \geq \pi_i^o \geq 0$$

This relationship can be rewritten as:

$$IR_i^d: \quad P_e x_d - M - \underbrace{\left[C^{h_d}\left(x_i\right) - C^o\left(x_i\right)\right]}_{Cost\ of\ adopting\ C^a\left(x_i\right)} = \Delta \geq 0$$

where the term $C^a\left(x_i\right) = C^{h_d}\left(x_i\right) - C^o\left(x_i\right)$ represents the cost of adopting the BMP and Δ is the benefit of the contract.

The participation constraint IR_i^d can also be interpreted as an isobenefit line since it shows the combination of P_e and M that provide the same level of contract benefits Δ. The equation of the isobenefit line IR_i^d in $\left(M, P_e\right)$ space takes the form:

$$\textbf{(6.3)} \quad P_e = \underbrace{\frac{C^a\left(x_i\right) + \Delta}{x_d}}_{Intercept} + \underbrace{\frac{1}{x_d}}_{Slope} M$$

Recall that there are two groups of farmers – those that sequester a small amount of carbon and those that sequester a large amount of carbon. The constraint lines for both groups in the default coefficient case have the same slope – $slope\ IR_l^d = slope\ IR_s^d = \frac{1}{x_d}$

– therefore the IR_i^d lines are parallel. The location of the IR^d curves relative to each other depends on the respective intercepts which in turn depends on the magnitude of the cost of adopting the BMP. Assuming the cost of adopting the BMP for the farmer in group l is not higher than the cost of adopting for the farmer in group s, the intercept of the IR_l^d curve will be smaller than or equal to the intercept of the IR_s^d curve (i.e., $\frac{C^a(x_l)+\Delta}{x_d} \leq \frac{C^a(x_s)+\Delta}{x_d}$)[11]. The feasible region, alternatively called the coalition region, is represented by the dashed area in Figure 6.3.

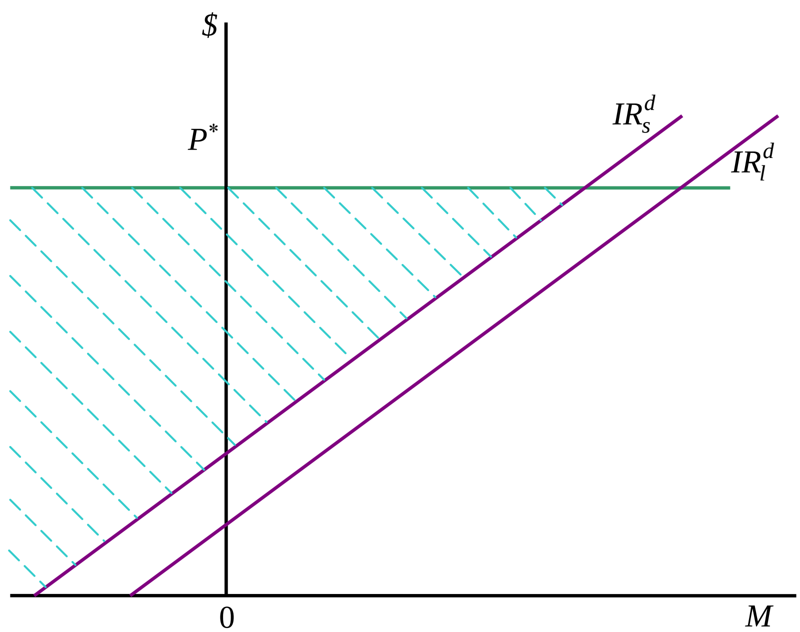


Figure 6.3 The coalition area in the default coefficient case

Suppose farmers are audited with a probability $\theta \in [0,1]$ and they face a per unit penalty γ if they are caught cheating on the contract. If a farmer cheats, his expected benefit depends on both the auditing probability as well as the penalty paid if he is

[11] The cost of adopting is given by the difference $C^a(x_i) = C^{h_d}(x_i) - C^o(x_i)$. Since the land size is the same, we suppose the cost $C^o(x_i)$ that farmer from each group incurs in case he does not sign the sequestration contract is the same. As a result, the following relation holds: $C^{h_d}(x_l) \leq C^{h_d}(x_s)$.

caught cheating. If he is not detected, he can enjoy the benefit $R+P_e x_d - C^{nh_d}(x_i) - M$ where $C^{nh_d}(x_i)$ is the cost incurred when the contract is not honoured. This term includes the transaction costs of signing the contract as well as the cheating cost (such as masquerading costs). If the farmer is caught cheating, he gets the benefit $R+P_e x_d - C^{nh_d}(x_i) - M - \gamma x_d$. As a result, the farmer's expected profit $\pi_i^{nh_d}$ from cheating (i.e. when he signs the contract but does not honour it) is given by:

(6.4) $\pi_i^{nh_d} = R+P_e x_d - C^{nh_d}(x_i) - M - \theta\gamma x_d$

The aggregator provides an incentive to farmers who sign the contract to comply with its terms only if the monitoring intensity θ is chosen such that the incentive compatibility constraint is satisfied. A farmer from group i who has already signed the contract will comply with its terms only if the profit from complying is higher than the expected profit from non-complying, i.e., if:

$IC_i^d : \ \pi_i^{h_d} > \pi_i^{nh_d}$ or

$$R+P_e x_d - C^{h_d}(x_i) - M > R+P_e x_d - C^{nh_d}(x_i) - M - \theta\gamma x_d$$

After making transformations, the following result is reached:

(6.5) $\theta\gamma x_d > C^{h_d}(x_i) - C^{nh_d}(x_i) = CHC^d(x_i)$

The term $CHC(x_i)$ on the right side represents the cost of honouring the contract (i.e., the compliance cost, assuming the farmer has already signed the contract). Recalling from footnote (5) that $C^{h_d}(x_l) \le C^{h_d}[x_s]$, we presume that $CHC^d(x_l) \le CHC^d(x_s)$, which means that the cost of honouring the contract for the farmers in group l is no higher than the cost of honouring the contract for the farmers in group s. The non-compliance penalty γx_d multiplied by the monitoring probability provides the expected non-compliance penalty. The result in equation 6.5 shows that the farmer complies with the contract if the expected penalty of non-compliance is greater than the cost of honouring the contract. The minimum inspection probability that ensures compliance of group i can be derived from $\theta_{i_d}^{min}\gamma x_d = CHC^d(x_i)$ and is equal to:

(6.6) $\theta_{i_d}^{min} = \dfrac{CHC^d\left(x_i\right)}{\gamma x_d}$.

This formula presents the well-known result in the enforcement literature that the probability of auditing is inversely proportional to the non-compliance penalty. The optimal inspection likelihood is proportional to the cost of honouring the contract; therefore $\theta_{l_d}^{min} \le \theta_{s_d}^{min}$. If the incidence of being inspected is different for farmers from different groups, a targeted monitoring will be required. The minimum inspection probability $\theta_{i_d}^{min}$ for each group will be such that there is just enough monitoring to that group to comply with the terms of the contract. If targeted monitoring is not possible, then compliance will be incomplete or excess resources will be used in monitoring.

6.2.1.1 Aggregator's Problem

Having explored the problem from the farmer's point of view, we now consider it from the aggregator's perspective. The number of the farmers in group s is denoted by N_s while the number of farmers in group l is denoted by N_l. The revenue R_p that the aggregator collects from the lump sum fee is equal to:

$R_p = N_s M + N_l M = NM$.

The aggregator's profit is given by the following expression:

(6.7) $\pi_p^d = NM + \left(P^* - P_e\right)\left(N_s x_d + N_l x_d\right) - \underbrace{\left[C\left(\theta_{l_d}^{min}\right) + C\left(\theta_{s_d}^{min}\right)\right]}_{C_m^d}$

where C_m^d denotes the monitoring cost in the default coefficient case. We have incorporated the incentive compatibility constraints in the profit function by substituting θ_i with θ_i^{min}. For each particular profit value $\overline{\pi}_p^d$, an isoprofit curve can be obtained. The isoprofit equation in $\left(M, P_e\right)$ space is given by:

(6.8) $\overline{\pi}_p^d : \; P_e = \underbrace{P^* - \dfrac{C_m^d}{Nx_d} - \dfrac{\overline{\pi}_p^d}{Nx_d}}_{Intercept} + \underbrace{\dfrac{1}{x_d}}_{Slope} M$

Note that the isoprofit lines for the aggregator have the same slope as the isobenefit (or participation) lines for the farmers, so the lines are parallel to each other.

At this point we need to differentiate between the two types of aggregators.

6.2.1.1.1 For-Profit Aggregator

If the aggregator operates on a for-profit basis, her objective function is to maximize profit. A rightward parallel shift of the isoprofit line causes an increase in the profit, thus the aggregator will try to locate the isoprofit line as far rightward as she can while still remaining in the feasible region.

The individual rationality constraint IR_i^d in this case will be binding; if it is not then the aggregator can increase profits by either decreasing the payment P_e or increasing the membership fee M. Thus, $\Delta = 0$ and the equation 6.3 representing the participation line $IR_i^{d^0}$ will be written as follows:

(6.9) $IR_i^{d^0} \; : \; P_e = \dfrac{C^a\left(x_i\right)}{x_d} + \dfrac{1}{x_d}M .$

The situation is represented in Figure 6.4. The aggregator shifts the isoprofit line until it reaches the $IR_s^{d^0}$ curve. For each point of the segment ab, both groups participate in the pool and the profit is maximized at $\overline{\pi}_{p.}^{d^{max}}$ Each point along the line segment ab represents a possible solution to the aggregator's pricing problem.

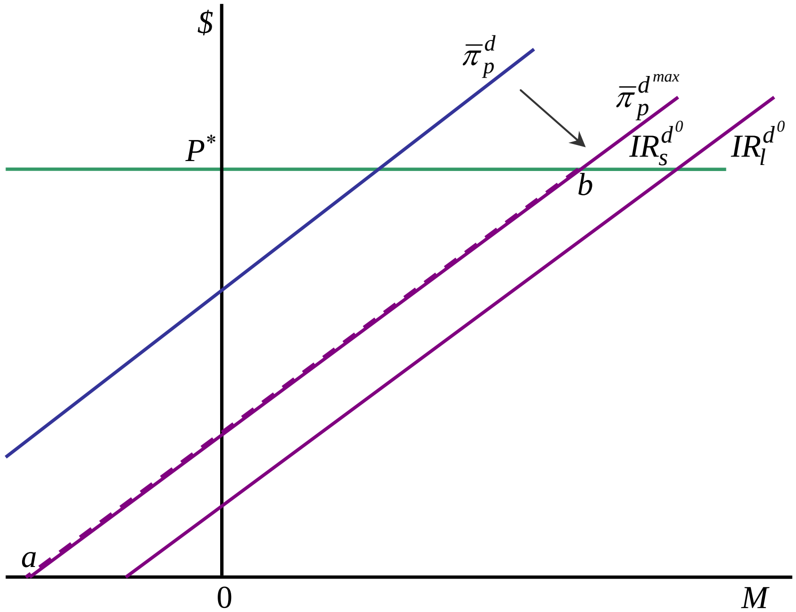


Figure 6.4 The default coefficient case when the pool is run on a for-profit basis. The case of a heterogeneous pool

So far this work has considered the case of a heterogeneous pool run on a for-profit basis. What would happen if the pool were created by assembling only farmers belonging to the same group?

Consider first the case of a pool formed only with farmers from group s. The monitoring cost in this homogeneous case, $C_{m_1}^d$, will differ from the monitoring cost in the heterogeneous case, C_m^d. The higher the monitoring probability, the higher is the cost of monitoring; thus the monitoring cost is an increasing function of the monitoring probability. Given that probability of monitoring farmers from group s is higher than the probability of monitoring farmers from group l (i.e, $\theta_{s_d}^{min} > \theta_{l_d}^{min}$), the monitoring cost $C_{m_1}^d > C_m^d$. The isoprofit equation will be rewritten as follows:

$$\overline{\pi}_{p_1}^d : \; P_e = \underbrace{P^* - \frac{C_{m_1}^d}{Nx_d} - \frac{\overline{\pi}_p^d}{Nx_d}}_{Intercept} + \underbrace{\frac{1}{x_d}}_{Slope} M .$$

Note that the intercept of the isoprofit line has decreased but the slope has not changed; thus the isoprofit lines still remain parallel to the isobenefit lines. Provided that the pool is formed solely with farmers from group s, only the participation line $IR_s^{d^0}$ should be considered in the diagram (see Figure 6.5). The isoprofit line $\overline{\pi}_{p_1}^d$ will shift in until it reaches the $IR_s^{d^0}$ curve. Any point in the line segment ab can be a solution. For the same profit value, the isoprofit line $\overline{\pi}_{p_1}^d$ is located to the right of the isoprofit line $\overline{\pi}_p^d$. Hence, the maximum profit value for the homogeneous pool case, $\overline{\pi}_{p_1}^{d^{max}}$ is smaller then the maximum profit value for the heterogeneous pool case, $\overline{\pi}_p^{d^{max}}$. We conclude that the FPA would not select to do the monitoring for a homogeneous group that includes only farmers from group s since it can get higher benefits by offering the monitoring service to a heterogeneous group.

Now suppose the pool is formed only with farmers from group l. The monitoring cost, $C_{m_2}^d$, will be lower in this case and the isoprofit equation will be given by:

$$\overline{\pi}_{p_2}^d : \quad P_e = \underbrace{P^* - \frac{C_{m_2}^d}{Nx_d} - \frac{\overline{\pi}_p^d}{Nx_d}}_{Intercept} + \underbrace{\frac{1}{x_d}}_{Slope} M .$$

Notice that the intercept of the isoprofit line $\overline{\pi}_{p_2}^d$ is higher than the intercept of the isoprofit line $\overline{\pi}_p^d$, but the slopes are the same. For the same profit value, the isoprofit line $\overline{\pi}_{p_2}^d$ will be located to the left of the isoprofit line $\overline{\pi}_p^d$. In this case only the individual rationality constraint $IR_l^{d^0}$ applies and the isoprofit line can be shifted out until it reaches this participation line. Each point from the segment fg can be a solution to the aggregator's problem. Since points along the line segment fg provide a higher profit level than the profit level in the case of a heterogeneous pool, the for-profit structure of the pool is likely to lead to a homogenous pool being formed with farmers that sequester large amounts of carbon.

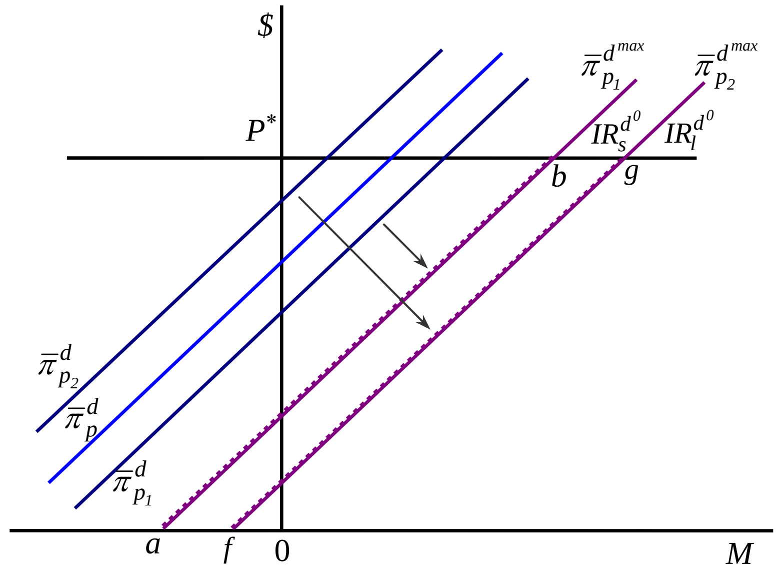


Figure 6.5 The default coefficient case when the pool is run on a for-profit basis. The case of a homogeneous pool

6.2.1.1.2 Producers' Association

The role of the aggregator can also be played by a PA formed by the farmers themselves. This type of aggregator differs from the former one in a number of aspects. Members of the PA can observe the contribution of the others and make this information available to the aggregator. It is in the interest of the members to make this information available to the aggregator since they are the users and the owners of the pool. In the previous case of the FPA, it was the aggregator who owned the business and the farmers were only using it; therefore the farmers would not supply the same type of information to the aggregator. More specifically, the information set for a pool owned and run by the farmers is superior to the one accessible to the FPA. The fact that the information sets are different has an impact on the monitoring costs. Because of this cross monitoring among members, the moral hazard is reduced and the PA can save on the monitoring costs. The difference in the monitoring costs due to the different information sets will be captured in the cost structure. The monitoring cost $C_m^{'d}$ for the PA which is expressed as follows:

$$C_m^{'d} = C'\left(\theta_{l_d}^{min}\right) + C'\left(\theta_{s_d}^{min}\right) < C_m^d$$

will be substituted for the C_m^d in the isoprofit equation.

In the profit function for the PA case we incorporate an additional cost component, F, which is the cost of organizing the pool. This cost includes the cost of such things as organizing meetings, discussing the idea of forming a PA, debating the activities that the pool might undertake, and developing the initial idea to a stage where it can be decided upon. These costs relate to the collective nature of the PA and are typically not incurred by a for-profit firm (Fulton, 2005). The PA can only be expected to form if:

$$\pi_p^d = NM + \left(P^* - P_e\right)\left(N_s x_d + N_l x_d\right) - C_m^{'d} - F \geq 0.$$

The PA will typically run on a break even basis. The FPA cannot charge the farmers more than the PA because it is a competition that FPA needs to meet. If the FPA were to do so, the farmers would form a PA. However, the presence of the cost F might allow the FPA to earn some profit while the PA breaks even.

Assuming PA operates on to break even, the aggregator will choose M and P_e so that the profit value $\overline{\pi}_p^d = 0.$ Under this assumption, the equation of the isoprofit curve $\overline{\pi}_p^{d^0}$ simplifies to the following:

$$\textbf{(6.10)} \quad \overline{\pi}_p^{d^o} : \; P_e = \left(P^* - \frac{C_m^{'d} + F}{N x_d} \right) + \frac{1}{x_d} M.$$

This isoprofit line shows the combination of price and lump sum fee (or the membership fee) that generates sufficient revenue to allow the pool to just break even.

As mentioned before, in the FPA case, the aggregator chooses the farmers' type while in the PA case, the farmers choose the type of the pool they form; thus the analysis for each of these cases is performed differently. The FPA chooses the alternative that provides her with the highest profit, whereas in the PA case the farmers choose the alternative that provides them the highest benefit.

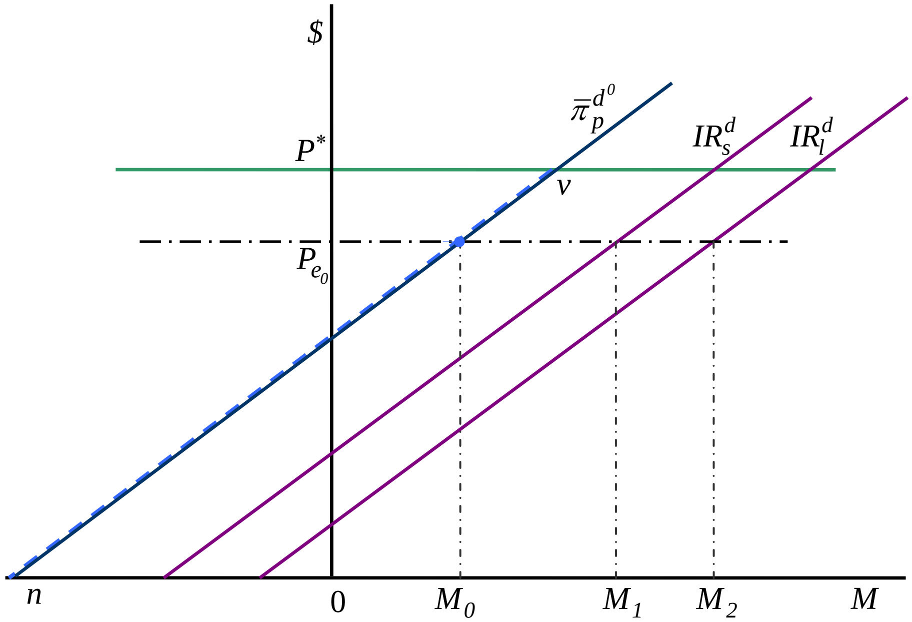


Figure 6.6 The default coefficient case when the structure of the pool is a PA. The heterogeneous pool case

In the case of a heterogeneous pool, each point on the segment nv can be a solution to the problem faced by the PA aggregator. This means that all the combinations of payments and membership fees along this segment provide a zero profit for the pool and meet all the criteria to be solutions to the problem; thus both individual rationality and incentive compatibility constraints are satisfied. Let us select one point from this segment which represents the solution $\left(P_{e_0}, M_0\right)$. Each farmer pays a membership fee of M_0 and gets paid a price of P_{e_0} per unit of carbon offset. But for this price, a farmer from group s would be willing to pay a membership of $M_1 > M_0$ and still participate in the pool, while a farmer from group l would have paid a membership $M_2 > M_1 > M_0$ and still participated in the pool. By paying a lower membership fee, both groups benefit from participating in the PA, but the farmers from group l, which are the farmers in the middle stage of sequestration, benefit the most. Thus, even if the aggregator is paying all the farmers for the same amount of carbon offsets x_d, it is the farmers from group l that benefit the most when participating in a heterogeneous pool.

What would happen if the pool was a homogeneous one?

Suppose the pool is formed solely with farmers from group l. The line $IR_l^{d^0}$ will be the only participation line that applies to this case. Following the same logic as in the FPA option, we come to the result that the monitoring cost, $C_{m_2}^{'d}$, in this homogeneous pool case is smaller than the monitoring cost in the heterogeneous pool case, i.e., $C_{m_2}^{'d} < C_m^{'d}$. As a result, when the homogeneous pool breaks even, the isoprofit line:

$$\overline{\pi}_{p_2}^{d^0} : \; P_e = \left(P^* - \frac{C_{m_2}^{'d} + F}{N x_d} \right) + \frac{1}{x_d} M$$

lies to the left of the isoprofit line $\overline{\pi}_p^{d^0}$. This means that the formation of a homogeneous pool with farmers from group l provides to the members a higher benefit than the formation of a heterogeneous pool.

What are the farmers from group s going to do now that the farmers from group l are grouped in a homogeneous pool? They might consider forming a PA on their own since they are left with no other option. The previous analysis showed that the FPA will not choose to offer the monitoring service to a homogeneous group with farmers from group s. The monitoring cost $C_{m_1}^{'d}$ applied to this homogeneous pool case is higher than the monitoring cost $C_m^{'d}$ applied to the heterogeneous pool case. For a zero profit value of the PA, the isoprofit line:

$$\overline{\pi}_{p_1}^{d^0} : \; P_e = \left(P^* - \frac{C_{m_1}^{'d} + F}{N x_d} \right) + \frac{1}{x_d} M$$

will be positioned to the right of the isoprofit line $\overline{\pi}_p^{d^0}$. As long as the isoprofit line $\overline{\pi}_{p_1}^{d^0}$ is still in the coalition region, the farmers from group s will form a PA of their own since they benefit from the formation. From the pool formation they can capture benefits that result from the economies of scale and from the grouping of resources.

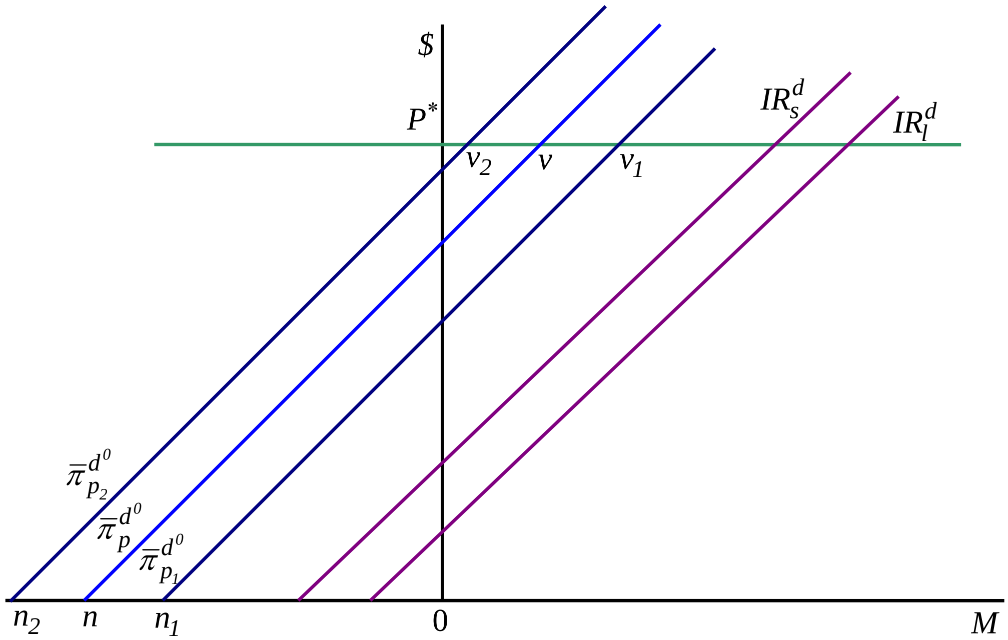


Figure 6.7 The default coefficient case when the structure is a PA.
The homogeneous PA case

We conclude that the break-even structure of the PA pool has potential to lead to the formation of a homogeneous pool assembling only farmers that are in the middle stage of sequestration and a homogeneous pool including only farmers from the other group s. The results obtained for the FPA and for the PA structures under the default coefficient case are summarized in Table 1.

Table 6.1. ***Summarizing the results obtained for each alternative in the default coefficient case***

Alternative			Solution	Coordinates of the solution	Profit
Default coefficient	FPA	Heterogeneous	Segment *ab* (Fig. 6.4)	***a***: $\left(-C^a\left(x_s\right);0\right)$; ***b***: $\left(P^* x_d - C^a\left(x_s\right);P^*\right)$	$\bar{\pi}_p^{d^{max}}$
Default coefficient	FPA	Homogeneous ***l***	Segment *fg* (Fig. 6.5)	***f***: $\left(-C^a\left(x_l\right);0\right)$; ***g***: $\left(P^* x_d - C^a\left(x_l\right);P^*\right)$	$\bar{\pi}_{p_2}^{d^{max}} > \bar{\pi}_p^{d^{max}}$
Default coefficient	FPA	Homogeneous ***s***	Segment *ab* (Fig. 6.5)	***a***: $\left(-C^a\left(x_s\right);0\right)$; ***b***: $\left(P^* x_d - C^a\left(x_s\right);P^*\right)$	$\bar{\pi}_{p_1}^{d^{max}} < \bar{\pi}_p^{d^{max}}$
Default coefficient	PA	Heterogeneous	Segment *nv* (Fig. 6.6)	***n***: $\left(-\left(P^* x_d - \frac{C'^d_m + F}{N}\right);0\right)$ ***v***: $\left(\frac{C'^d_m + F}{N};P^*\right)$	$\bar{\pi}_p^{d^o} = 0$
Default coefficient	PA	Homogeneous ***l***	Segment n_2v_2 (Fig. 6.7)	$\boldsymbol{n_2}$: $\left(-\left(P^* x_d - \frac{C'^d_{m_2} + F}{N}\right);0\right)$ $\boldsymbol{v_2}$: $\left(\frac{C'^d_{m_2} + F}{N};P^*\right)$	$\bar{\pi}_{p_2}^{d^o} = 0$
Default coefficient	PA	Homogeneous ***s***	Segment n_1v_1 (Fig. 6.7)	$\boldsymbol{n_1}$: $\left(-\left(P^* x_d - \frac{C'^d_{m_1} + F}{N}\right);0\right)$ $\boldsymbol{v_1}$: $\left(\frac{C'^d_{m_1} + F}{N};P^*\right)$	$\bar{\pi}_{p_1}^{d^o} = 0$

So far, the analysis of this chapter has been focused in the general case when the cost of adopting, and as a result, the cost of honouring the contract were considered as different for farmers belonging to different groups. A reasonable scenario would be one with equal cost of adopting for all farmers that undertake a BMP. The argument for this would be that what is really different is the sequestration phase that farmers are in, not the BMP they have undertaken; thus the costs of adopting the practice could be considered the same for all farmers – i.e., $C^a\left(x_l\right) = C^a\left(x_s\right)$. In this case, the isobenefit lines for farmers from both groups will overlap and the probability of monitoring farmers from group l will be the same as the probability of monitoring farmers from group s – i.e., $\theta_{l_d}^{min} = \theta_{s_d}^{min}$; thus the isoprofit lines $\bar{\pi}_p^d$, $\bar{\pi}_{p_2}^d$ and $\bar{\pi}_{p_1}^d$ will overlap too.

Figure 6.8 represents the heterogeneous and the homogeneous pool cases when the pool is run on a for-profit basis. The feasible region is the same for both these cases. The maximum profit will be attained along segment $a'b'$ since this is the farthest part in the feasible region where the aggregator can position the isoprofit line. Note that the same solution is obtained when considering the formation of a heterogeneous pool as it is when considering the founding of a homogeneous pool of each type. If the costs of adopting the BMP are the same for each farmer regardless of which group they belong to, a heterogeneous pool would be stable and neither a heterogeneous pool, nor a homogeneous pool, is strictly preferred to the other.

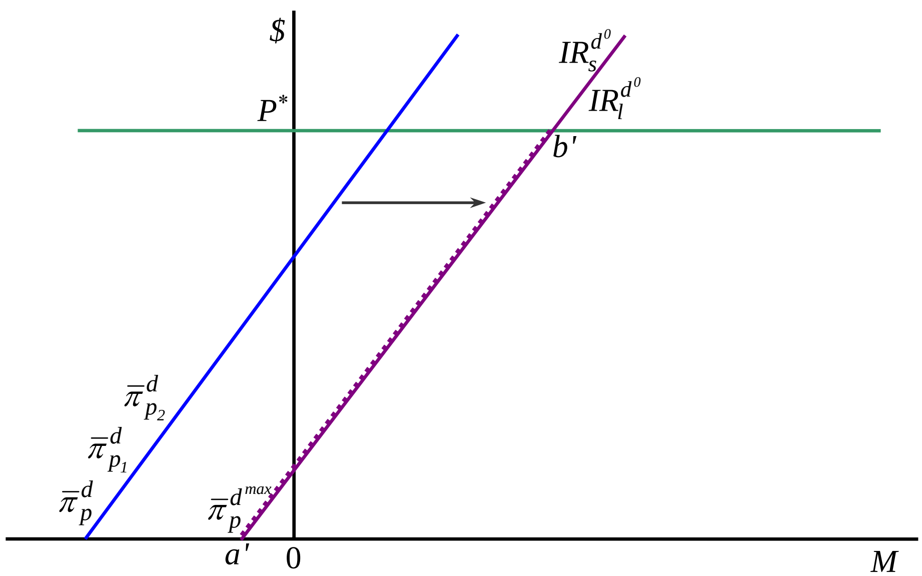


Figure 6.8 The default coefficient case when the costs of adopting are the same. The homogeneous & heterogeneous pool cases when the pool is run on a FP basis

Figure 6.9 represents the heterogeneous and the homogeneous pool cases when the pool is run on a break-even basis. Since the isobenefit lines IR_s^d and IR_l^d overlap, the coalition area is the same for the heterogeneous and for the homogeneous cases. In the case of a heterogeneous pool, farmers from each of the two groups benefit the same from participating in the pool and this is given by the difference between the isoprofit line $\bar{\pi}_{p}^{d^0}$ and the isobenefit lines IR_s^d or IR_l^d. Notice that this result has changed from the result we obtained in the general case.

The incidence of being inspected is the same for both groups of farmers; therefore the isoprofit lines $\bar{\pi}_{p}^{d^0}$, $\bar{\pi}_{p_1}^{d^0}$ and $\bar{\pi}_{p_2}^{d^0}$ overlap. In the case of a homogeneous pool formed with farmers from group l, the benefit to the farmers (i.e., the difference between the isoprofit line $\bar{\pi}_{p_2}^{d^0}$ and the isobenefit line IR_l^d) is equal to the benefit they would get from the formation of a heterogeneous pool. In the case of a homogeneous pool formed with farmers from group s, the benefit to the farmers (i.e., the difference between the isoprofit line $\bar{\pi}_{p_1}^{d^0}$ and the isobenefit line IR_s^d) is the same as the benefit they would get from the formation of a heterogeneous pool. Hence, a heterogeneous pool would be stable under this scenario and neither a heterogeneous pool nor a homogeneous pool would be strictly preferred to the other.

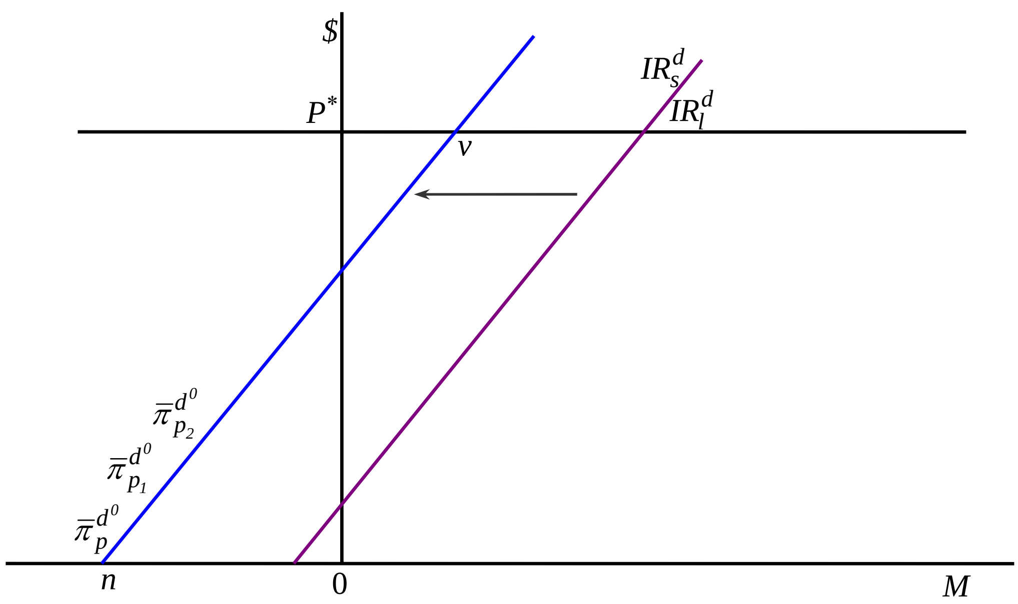


Figure 6.9 The default coefficient case when the costs of adopting are the same. The homogeneous & heterogeneous pool cases under a PA structure

6.2.2 Custom Coefficient Case

Consider now the custom coefficients case. The aggregator introduces two contracts. A farmer who is in the early or the late stage of sequestration produces a smaller amount of carbon offsets than does a farmer who is in middle stage of sequestration; therefore the pool assigns a smaller coefficient to the farmers from group s than to the ones from group l. Each farmer pays the lump sum fee M and in return gets paid price P_e for the amount x_s of carbon offsets if he belongs to group s or for the amount $x_l > x_s$ of carbon offsets if he belongs to group l of farmers.

Under the custom coefficients case, the aggregator needs to collect information about the stage of sequestration for farmers belonging to each group. Farmers provide this information by submitting a historical plan of their soil management activity to the aggregator. As a result, the aggregator will know the type of each farmer and can thus undertake different levels of monitoring for the two groups. She can also pay different lump sum fees M_i or unit prices P_{e_i} for farmers from the different groups; however, the analysis is kept simple by continuing to consider the simple two part tariff described in the previous section.

If the farmer does not sign the carbon sequestration contract, his profit is the same as in the default coefficient case (see equation 6.1). The profit $\pi_i^{h_c}$ that the farmer obtains if he signs the contract, participates in the pool and honours its terms is given as:

(6.11) $\pi_i^{h_c} = R + P_e x_i - C^{h_c}\left(x_i\right) - M$

where $C^{h_c}\left(x_i\right)$ is the cost incurred. This term includes the sequestration cost, the transaction cost of signing the contract as well as the costs of keeping records and reporting. The cost incurred to the farmer who signs the contract and honours its provisions is lower in the default coefficient case than in the custom coefficients case since the farmer was not incurring the cost of keeping records and reporting in the former case – i.e., $C^{h_c}\left(x_i\right) > C^{h_d}\left(x_i\right)$.

The profit $\pi_i^{nh_c}$ symbolizes the farmer's expected profit if he signs the sequestration contract but does not comply with all its terms. As was discussed earlier, the pool undertakes monitoring in order to induce farmers' compliance with the terms of the contract they sign with the pool. The probability of monitoring farmers is denoted by θ and the penalty per unit of cheating is γ. The fixed per unit penalty is exogenous to the pool and the only enforcement tool that the pool can control is the monitoring frequency.

The farmer's expected profit $\pi_i^{nh_c}$ is:

$$\pi_i^{nh_c} = \theta\left[R + P_e x_i - C^{nh_c}\left(x_i\right) - M - \gamma x_i\right] + \left(1-\theta\right)\left[R + P_e x_i - C^{nh_c}\left(x_i\right) - M\right]$$

which implies that:

(6.12) $$\pi_i^{nh_c} = R + P_e x_i - C^{nh_c}\left(x_i\right) - M - \theta\gamma x_i$$

where $C^{nh_c}\left(x_i\right)$ represents the cost that farmer experiences in this case. This term contains the transaction cost of signing the contract as well as the cost of cheating (e.g. double-bookkeeping).

Each farmer participates in the pool only if he obtains a profit from participation which is at least as large as the profit from non participation. Under the custom coefficients' case, the individual rationality constraint for a farmer from group i is:

$IR_i^c : \ \pi_i^{h_c} \geq \pi_i^o \geq 0$ or

(6.13) $$IR_i^c : \ P_e x_i - M - \underbrace{\left[C^{h_c}\left(x_i\right) - C^o\left(x_i\right)\right]}_{Cost\ of\ adopting\ C^{a'}\left(x_i\right)} = \Delta' \geq 0$$

where the term $C^{a'}\left(x_i\right) = C^{h_c}\left(x_i\right) - C^o\left(x_i\right)$ represents the cost of adopting the BMP.

The participation constraints IR_s^c and IR_l^c define the feasible area in which the price P_e and the membership M are such that the members of both groups prefer to participate in the pool. The equation of the participation line IR_i^c in $\left(M, P_e\right)$ space takes the form:

(6.14) $$P_e = \underbrace{\frac{C^{a'}\left(x_i\right) + \Delta'}{x_i}}_{Intercept} + \underbrace{\frac{1}{x_i}}_{Slope} M$$

The participation line for group s is steeper than the participation line for group l because $slope\ IR_s^c = \frac{1}{x_s} > \frac{1}{x_l} = slope\ IR_s^c$. The feasible region is represented in figures 6.10 and 6.11, which illustrate the two cases that can occur depending on the magnitude of the intercept term (case 2 illustrates the situation where the intercept of IR_s^c is relatively small).

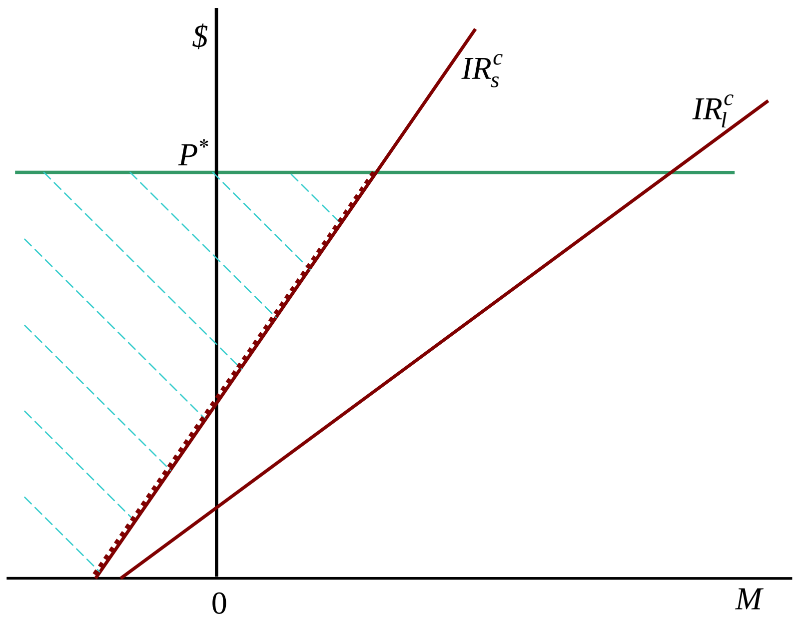


Figure 6.10 The coalition area in the custom coefficients' option (Case 1)

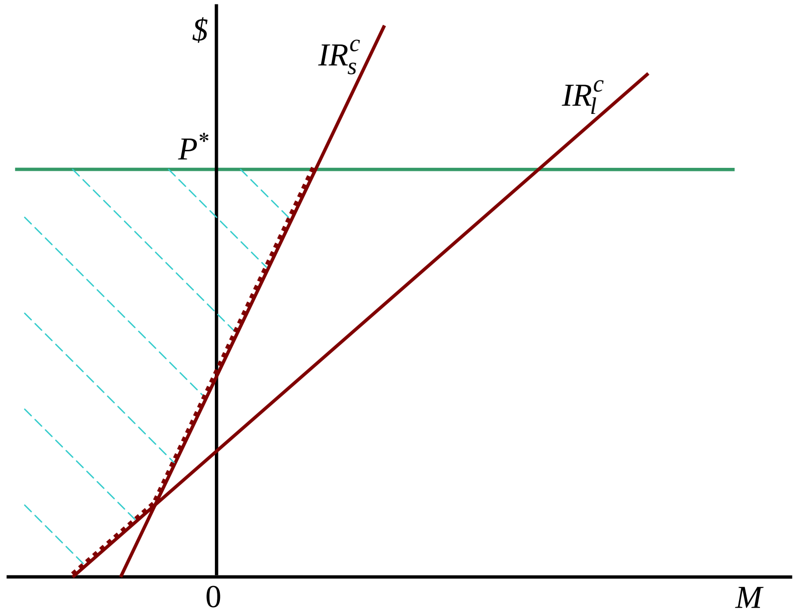


Figure 6.11 The coalition area in the custom coefficients' option (Case 2)

The aggregator provides an incentive to a farmer who signs the contract to comply with its terms only if she chooses the monitoring probability such that the following incentive compatibility constraint is satisfied:

$IC_i^c : \pi_i^{h_c} > \pi_i^{nh_c}$

This inequality can be written as:

(6.15) $R + P_e x_i - C^{h_c}(x_i) - M > R + P_e x_i - C^{nh_c}(x_i) - M - \theta\gamma x_i$

Further simplification of this equation gives:

(6.16) $\theta\gamma x_i > C^{h_c}(x_i) - C^{nh_c}(x_i) = CHC^c(x_i)$

Equation 6.16 allows us to derive the minimum inspection probability that ensures compliance of group i:

(6.17) $\theta_{i_c}^{min} = \dfrac{CHC^c(x_i)}{\gamma x_i}$.

The optimal inspection likelihood is proportional to the per unit cost of honouring the contract. Given that $x_l > x_s$, the optimal monitoring probability is smaller for the farmers in group l, i.e., $\theta_{l_c}^{min} < \theta_{s_c}^{min}$.

6.2.2.1 Aggregator's Problem

Consider now the problem from the aggregator's perspective. The profit of the aggregator, π_p^c, is given as:

$$\textbf{(6.18)}\quad \pi_p^c = NM + \left(P^* - P_e\right)\left(N_s x_s + N_l x_l\right) - \underbrace{\left[C\left(\theta_{l_c}^{min}\right) + C\left(\theta_{s_c}^{min}\right)\right]}_{C_m^c}$$

where C_m^c denotes the monitoring cost in the custom coefficients' case. As we have argued earlier the monitoring cost in the custom coefficient case is higher than the monitoring cost in the default coefficient case, i.e., $C_m^c > C_m^d$.

The isoprofit line equation in $\left(M, P_e\right)$ space is given by:

$$\textbf{(6.19)}\quad \overline{\pi}_p^c :\ \ P_e = \underbrace{P^* - \frac{C_m^c}{\left(N_s x_s + N_l x_l\right)} - \frac{\overline{\pi}_p^c}{\left(N_s x_s + N_l x_l\right)}}_{Intercept} + \underbrace{\frac{N}{\left(N_s x_s + N_l x_l\right)}}_{Slope} M$$

The slope of the isoprofit lines compares to the slopes of the participation lines as follows:

$$slope\ IR_l^c = \frac{1}{x_l} = \frac{N_s + N_l}{N_s x_l + N_l x_l} < slope\ \pi_p^c = \frac{N_s + N_l}{N_s x_s + N_l x_l} < slope\ IR_s^c = \frac{1}{x_s} = \frac{N_s + N_l}{N_s x_s + N_l x_s}$$

The participation line for group s is the steepest, while the participation line for group l is the flattest.

6.2.2.1.1 For-Profit Aggregator

A rightward parallel shift of the isoprofit line $\overline{\pi}_p^c$ causes an increase in the profit of the aggregator. Since the aggregator is a profit maximizer, she will try to locate the isoprofit line as far rightward as is possible in the coalition area. The result is that the individual rationality constraint IR_i^c is binding – i.e., $\Delta' = 0$. With $\Delta' = 0$, the equation of the participation line $IR_i^{c^0}$ can be simplified as:

$$\textbf{(6.20)}\quad IR_i^{c^0} :\ \ P_e = \frac{C^{a'}\left(x_i\right)}{x_i} + \frac{1}{x_i} M$$

In the first situation represented in Figure 6.12, the point $\left(-M_1, 0\right)$ is the solution to the aggregator's profit problem. In this solution, the aggregator pays each farmer a lump sum fee of M_1 and, by this way of payment, he ensures the participation of farmers from both groups as well as maximizes profits at $\overline{\pi}_{p.}^{c^{max}}$

In the case of a homogeneous pool formed with farmers from group l, the only participation line applicable is the line $IR_l^{c^0}$. We denote by $C_{m_2}^c$ the monitoring cost in this homogeneous pool case. Since the probability of monitoring farmers from group l is smaller than the probability of monitoring farmers from group s (i.e, $\theta_{l_c}^{min} < \theta_{s_c}^{min}$), the monitoring cost $C_{m_2}^c < C_m^c$. The isoprofit equation will be rewritten as follows:

$$\overline{\pi}_{p_2}^c : \quad P_e = \underbrace{P^* - \frac{C_{m_2}^c}{\left(N_s x_s + N_l x_l\right)} - \frac{\overline{\pi}_p^c}{\left(N_s x_s + N_l x_l\right)}}_{Intercept} + \underbrace{\frac{N}{\left(N_s x_s + N_l x_l\right)}}_{Slope} M$$

Note that only the slope of the isoprofit line has not changed. For the same profit value, the isoprofit line $\overline{\pi}_{p_2}^c$ will lie to the left of the isoprofit line $\overline{\pi}_p^c$ and thus to the left of $\overline{\pi}_p^{c^{max}}$. The solution of the homogeneous pool case under consideration is at point h. The isoprofit line $\overline{\pi}_{p_2}^c$ shifts in until it reaches this point; thus increasing the profit level attained by the FPA. By receiving a lump sum fee of M_2 from each farmer and by paying them back a price of P^* per unit of carbon offset, the aggregator maximizes its profit. This maximum profit level is higher than the maximum profit level in the case of a heterogeneous pool.

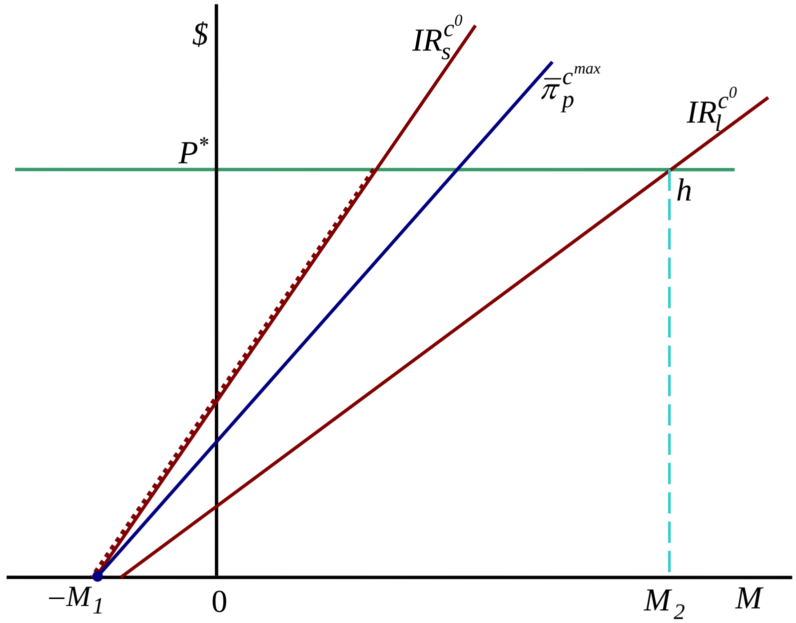


Figure 6.12 The solution for a FPA under the custom coefficients' alternative (Case 1)

If the pool were homogeneous with farmers from group s, the only participation line to be considered would be the line $IR_s^{c^0}$. The cost of monitoring $C_{m_1}^c$ will be higher than the cost of monitoring, C_m^c, in the heterogeneous case. As a result, for the same profit value, the isoprofit line:

$$\bar{\pi}_{p_1}^c: \quad P_e = \underbrace{P^* - \frac{C_{m_1}^c}{\left(N_s x_s + N_l x_l\right)} - \frac{\bar{\pi}_p^c}{\left(N_s x_s + N_l x_l\right)}}_{Intercept} + \underbrace{\frac{N}{\left(N_s x_s + N_l x_l\right)}}_{Slope} M$$

will always be located to the right of the heterogeneous case isoprofit line $\bar{\pi}_p^c$. Given that the solution is located at point $-M_1$ for both cases, we conclude that the FPA attains a higher profit level in the case of a heterogeneous pool than in the case of a homogeneous pool formed with farmers from group s. The FPA would not choose to offer the monitoring service to a pool that includes only farmers from group s since she can get a higher profit by offering the service to a heterogeneous pool and the highest profit by offering the service to a homogeneous pool formed with farmers that are in the middle stage of sequestration.

Figure 6.13 represents the second possibility that can arise in the custom coefficients' case. The solution to the problem in this case is at point $\left(-M_3, P_{e_3}\right)$. The aggregator ensures full participation as well as maximizes her profit by paying each farmer a lump sum fee of M_3 and a price of P_{e_3} per each unit of carbon offsets supplied.

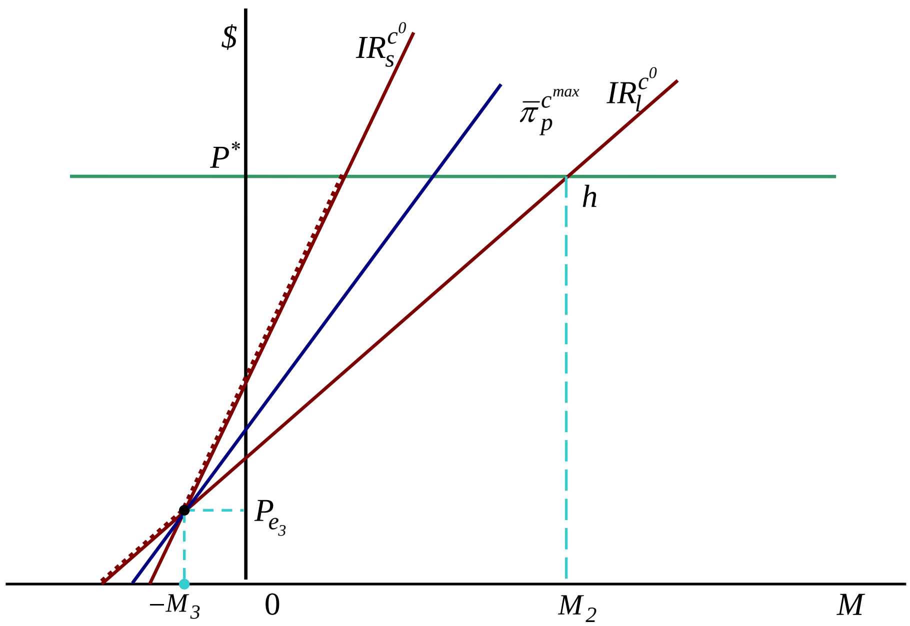


Figure 6.13 The solution for a FPA under the custom coefficients' alternative (Case 2)

In the case of a homogeneous pool composed of farmers from group l, the solution is at point h, which means that the FPA maximizes her profit by charging each farmer a lump sum fee of M_2 and paying him a price P^* per each unit of carbon offsets. Since the isoprofit line for this homogeneous case is located to the left of the isoprofit line for the heterogeneous case, we conclude that the maximum profit level attained by the FPA is higher in the case of the homogeneous pool formed with farmers from group l. Thus, the for-profit structure will most likely lead to a homogeneous pool formed with farmers from the middle stage of sequestration.

6.2.2.1.2 Producers' Association

The PA chooses the membership M and per unit price P_e so as to break even. With $\overline{\pi}_p^d = 0,$ the equation of the isoprofit curve $\overline{\pi}_p^{d^0}$ can be simplified as follows:

$$\textbf{(6.21)} \quad \overline{\pi}_p^{c^0} : \; P_e = P^* - \frac{C_m^{'c} + F}{\left(N_s x_s + N_l x_l\right)} + \frac{N}{\left(N_s x_s + N_l x_l\right)} M$$

The situation is represented in Figure 6.14. The aggregator can choose any combination of M and P_e along the segment tj since this ensures the participation of both groups and the fulfillment of the break even condition. If the aggregator chooses point t as a solution, he has to pay each farmer a lump sum fee equal to $0t$. A farmer from group s would still participate in the PA even if he would be paid a lump sum fee equal to $0u;$ thus this farmer receives a benefit equal to the difference $\left(0t - 0u\right)$ if point t were to be chosen as the solution. Similarly, a farmer from group l would benefit by an amount equal to the difference $\left(0t - 0z\right)$ if point t were selected by the aggregator. Both groups benefit from this choice, but a farmer from group l benefits more than a farmer from group s.

If the aggregator were to choose point j as a solution, he will collect from each farmer a lump sum fee of M_4 and will pay in return the price P_{e_4} for each unit of carbon offsets supplied. For this unit price, a farmer from group l would have paid a membership fee of M_5 and still joined the PA. The fact that he is paying only a membership fee of M_4 means that this farmer is benefiting by an amount equal to the difference $\left(M_5 - M_4\right)$ when point j is chosen as a solution by the aggregator. In contrast, a farmer from group s would just be indifferent between joining the PA and not joining it. Farmers from group s benefit the most if point t is selected, while farmers from group l benefit the most if point j is chosen. Which of the points on segment tj would be chosen as the solution depends on the bargaining and/or political power of the two groups.

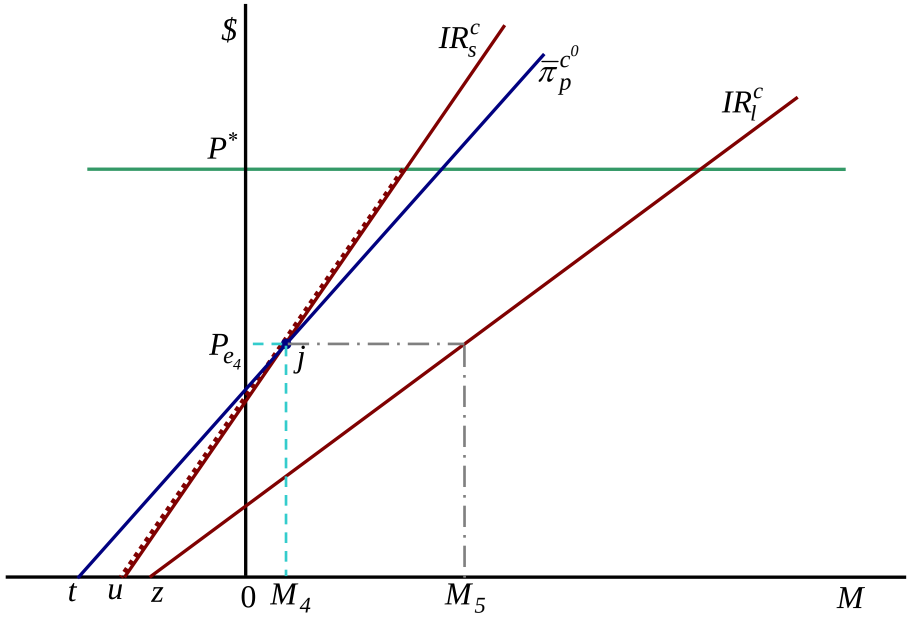


Figure 6.14 The solution for a PA under the custom coefficients' alternative (Case 1)

If the pool were homogeneous with farmers from group l, the only participation line applicable would be the line IR_l^c. The probability of monitoring $C_{m_2}^c$ in this homogeneous pool case is smaller than the monitoring probability, C_m^c, in the heterogeneous pool case. For a break even situation, the isoprofit line:

$$\bar{\pi}_{p_2}^{c^0} : \; P_e = P^* - \frac{C_{m_2}^{'c} + F}{(N_s x_s + N_l x_l)} + \frac{N}{(N_s x_s + N_l x_l)} M$$

will be located to the left of the isoprofit line $\bar{\pi}_p^{c^0}$. As shown in Figure 6.15, the solution will be at point r; thus farmers in group l benefit more from forming a homogeneous PA than a heterogeneous PA. Since the farmers from group s, are left out of the pool, they might consider forming a PA of their own in order to get benefits from both grouping the resources and the associated economies of scale.

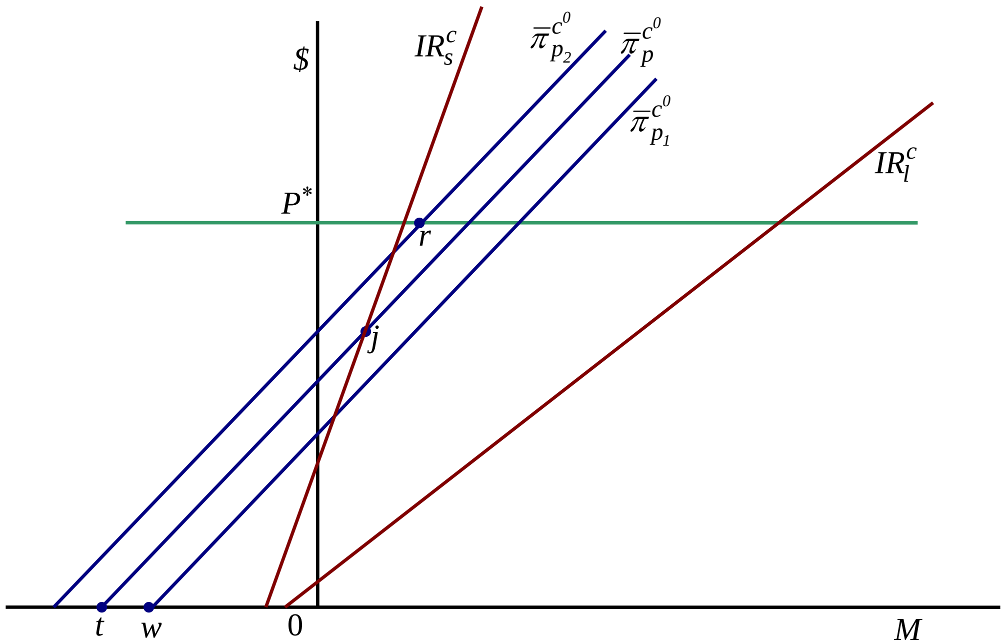


Figure 6.15 The solution for a PA under the custom coefficients' alternative. The consideration of a homogeneous PA (Case 1)

The probability of monitoring $C_{m_1}^c$ in this case will be higher than the monitoring probability C_m^c; thus the isoprofit line:

$$\overline{\pi}_{p_1}^{c^0}: \quad P_e = P^* - \frac{C_{m_1}^{'c} + F}{\left(N_s x_s + N_l x_l\right)} + \frac{N}{\left(N_s x_s + N_l x_l\right)} M$$

will be located to the right of the isoprofit line $\overline{\pi}_p^{c^0}$. The solution will be represented by point w. This means that these farmers benefit less from the formation of a PA of their own than by the formation of a heterogeneous pool, yet they will consider forming the pool on their own since they have no other option.

We conclude that the PA structure most likely leads to a homogeneous pool that assembles farmers that are in the middle stage of sequestration and a homogeneous pool formed with farmers from group s.

The interpretation in the second situation represented in Figure 6.16 is similar to the interpretations in the first situation. Farmers from group s would benefit the most if point t would be selected as the solution while farmers from group l would benefit the most if point j would be chosen as the solution by the aggregator. Which point on the segment tj would be chosen as the solution would depend on the bargaining or political power of the two groups of farmers.

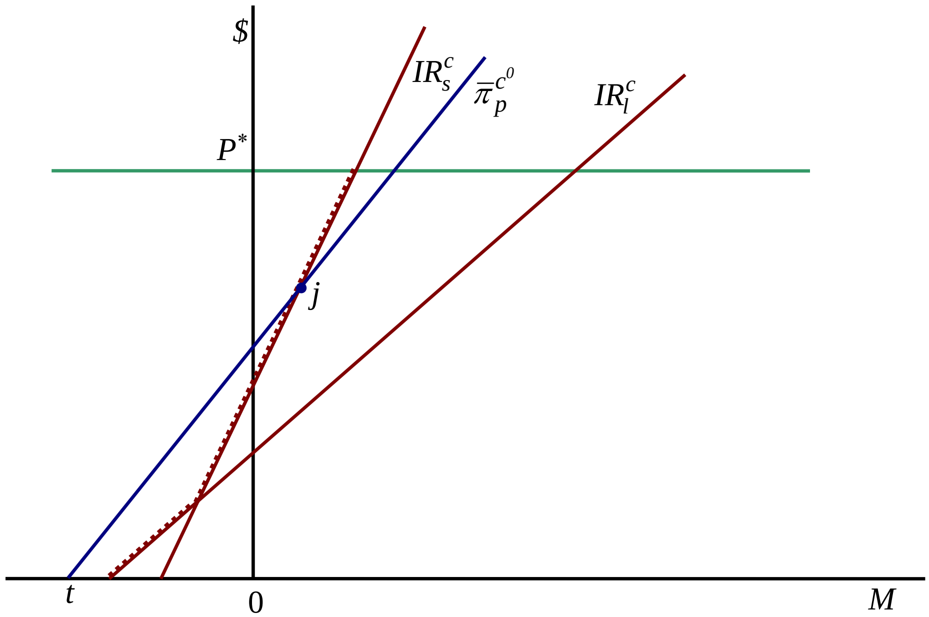


Figure 6.16 The solution for a PA under the custom coefficients' alternative (Case 2)

If farmers that are in the middle stage of sequestration form a PA of their own, only the participation line IR_l^c is applicable. The monitoring cost, $C_{m_2}^{'c}$, related to this homogeneous pool case is lower than the monitoring cost, $C_m^{'c}$, related to the heterogeneous pool case. As a result, the isoprofit $\overline{\pi}_{p_2}^{c^0}$ for a break even situation of the homogeneous pool will lie to the left of the isoprofit line $\overline{\pi}_p^{c^0}$ (see Figure 6.17). The solution will be located at point $r;$ hence the farmers that are in the middle stage of sequestration benefit more from the formation of a homogeneous pool than a heterogeneous pool.

If the farmers from group l form a homogeneous pool, the farmers from group s will also consider forming a pool of their own. In this case, only the participation line IR_s^c is applicable. The monitoring cost, which is denoted by $C_{m_1}^{'c}$, is higher than the monitoring cost $C_m^{'c}$ in the heterogeneous case; thus the isoprofit $\bar{\pi}_{p_1}^{c^0}$ will be positioned to the right of the isoprofit line $\bar{\pi}_p^{c^0}$. The solution will be located at point w, which means that the farmers in group s benefit less from the formation of a homogeneous group of their own than from the formation of a heterogeneous pool. Still, they will consider their homogeneous pool formation since they can get some benefits from it.

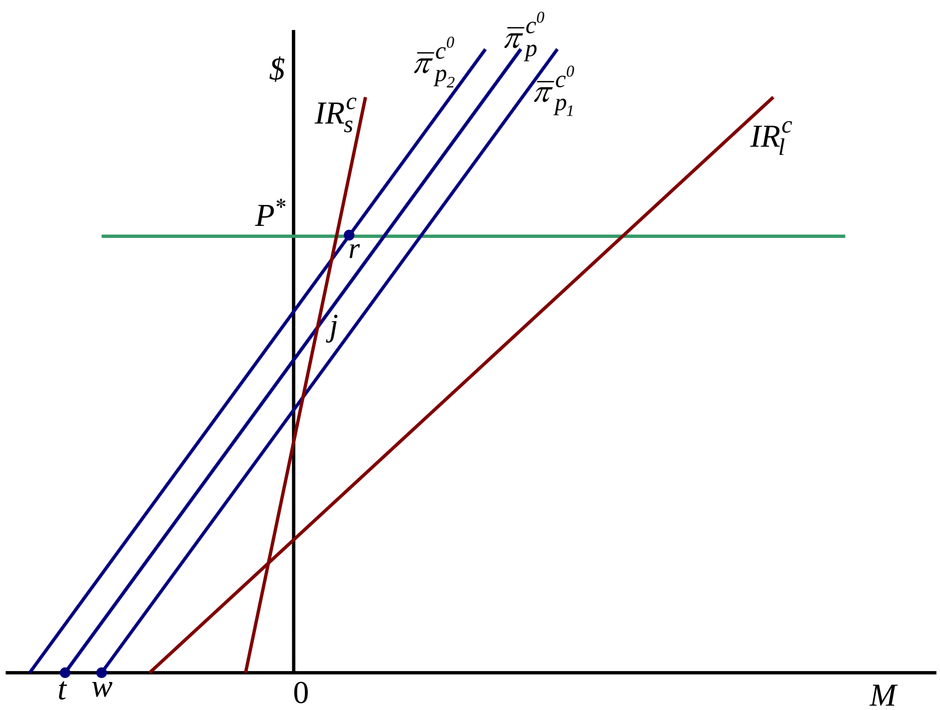


Figure 6.17 The solution for a PA under the custom coefficients' alternative. The consideration of a homogeneous PA (Case 2)

Table 2 summarizes the results obtained from exploring the FP and the PA alternatives under the custom coefficient case.

Table 6.2. ***Summarizing the results obtained for each alternative in the custom coefficients' case***

Alternative			***Solution***	***Coordinates of the solution***	***Profit***
Custom coefficient	**FPA**	Heterogen.	Point -M_1	-M_1: $\left(-C^{a'}\left(x_s\right);0\right)$	$\overline{\pi}_{p}^{c^{max}}$
			$\left(-M_3;P_{e_3}\right)$	$-M_3=\dfrac{C^{a'}\left(x_l\right)x_s-C^{a'}\left(x_s\right)x_l}{x_l-x_s}$ $P_{e_3}=\dfrac{C^{a'}\left(x_l\right)x_s-C^{a'}\left(x_s\right)x_s}{x_s\left(x_l-x_s\right)}$	
		Homogen. ***l***	Point *h*	*h*: $\left(P^{*}x_l-C^{a'}\left(x_l\right);P^{*}\right)$	$\overline{\pi}_{p_2}^{c^{max}}>\overline{\pi}_{p}^{c^{max}}$
		Homogen. ***s***	Point -M_1	-M_1: $\left(-C^{a'}\left(x_s\right);0\right)$	$\overline{\pi}_{p_1}^{d^{max}}<\overline{\pi}_{p}^{d^{max}}$
	PA	Heterogen.	Segment *tj* (Fig. 6.14)	$t:\left(-\left(\dfrac{P^{*}\left(N_s x_s+N_l x_l\right)}{N}-\dfrac{C_m^{'c}+F}{N}\right);0\right)$ For point j see Appendix 6 (long formula)	$\overline{\pi}_{p}^{c^{o}}=0$
		Homogen. ***l***	Point *r*	$r:\left(\dfrac{C_{m_2}^{'c}+F}{N};P^{*}\right)$	$\overline{\pi}_{p_2}^{c^{o}}=0$
		Homogen. ***s***	Point *w*	$M_w=-\left(\dfrac{P^{*}\left(N_s x_s+N_l x_l\right)}{N}-\dfrac{C_{m_1}^{'c}+F}{N}\right)$	$\overline{\pi}_{p_1}^{c^{o}}=0$

These findings resulted from analyzing the general case where the costs of adopting the BMP were considered to be different for farmers belonging to different groups. A reasonable scenario would be one that considers these costs of adopting as equal – i.e., $C^{a'}\left(x_s\right)=C^{a'}\left(x_l\right)$. The rationale for this consideration would be the same one used in the default coefficient case. The feasible region is illustrated as in Figure 6.10 and Figure 6.11. The incidence of being inspected is different for farmers belonging to different groups; therefore the isoprofit lines for the heterogeneous case and for the homogeneous cases will not overlap. The solutions for the FPA case will be located as represented in Figure 6.12 and Figure 6.13, while the solutions for the PA case will be positioned as presented in Figures 6.14, 6.15, 6.16 and 6.17. Once more we observe that the PA structure leads to the formation of a homogeneous pool of farmers who are in the middle stage of sequestration and a homogeneous pool with farmers from group s.

6.3 COMPARING THE ALTERNATIVES

So far we have considered two alternatives for the structure of the aggregator and two alternatives for the coefficients that might be used from the aggregator. The work that follows will focus on comparing those alternatives to each other in order to see which type of coefficient works better under different circumstances. The comparison will be performed under the supposition of equal costs of adopting for the farmers from both groups as a reasonable scenario.

6.3.1 Default coefficient versus custom coefficients for the FPA case

In the custom coefficients case, the FPA chooses to offer the monitoring service only to a homogeneous group with farmers that are in the middle stage of sequestration, while in the default coefficient case the FPA receives the same benefits providing the monitoring to a homogeneous pool or a heterogeneous pool. In assessing the two types of coefficients for the FPA structure, this section will compare only the cases of a homogeneous pool formed with farmers that are in the middle stage of sequestration when each type of coefficient is used.

The solution in the default coefficient case can be any point in segment $a'b'$ (Figure 6.8), while in the custom coefficient case the solution is point h (Figure 6.12). The comparison of the two alternatives will consist in comparing the abscissas of points b' and h to each other.

If $\underbrace{P^* x_l - C^{a'}\left(x_l\right)}_{absc.\ of\ h} > \underbrace{P^* x_d - C^{a}\left(x_l\right)}_{absc.\ of\ b'}$, the FPA will prefer the custom coefficient alternative to the default coefficient alternative, and vice versa.

6.3.2 Default coefficient versus custom coefficients for the PA case

The analysis of the reasonable scenario performed for the PA case showed that, under the custom coefficients option, the tendency is for the formation of a homogeneous pool with farmers from group l and a homogeneous pool with farmers from group s. On the other hand, the analysis in the default coefficient option showed that the farmers benefit the same from the formation of a heterogeneous pool as they do from the formation of a homogeneous pool of their own. In comparing the two coefficient alternatives for the PA structure, this section will assess only the homogeneous pool cases for each type of coefficient. The following analysis will reveal which type of coefficient the farmers from group l prefer to be used and which type of coefficient the farmers from group s wish to be used.

First we make the comparison of the two coefficient alternatives for a homogeneous PA with farmers from group l. The solution in the custom coefficient case is located at point r, while the solution in the default coefficient case can be any point in segment nv. The situation is presented in the left diagram in Figure 6.18. In order to assess the two coefficient alternatives, it is sufficient to compare the abscissas of points r and v.

Since $C'^{c}_{m_2} > C'^{d}_{m_2} \Rightarrow \underbrace{\frac{C'^{c}_{m_2} + F}{N}}_{absc.\ of\ r} > \underbrace{\frac{C'^{d}_{m_2} + F}{N}}_{absc.\ of\ v}$,

we conclude that farmers in group l who form a homogeneous PA benefit more under the default coefficient option than under the custom coefficients option.

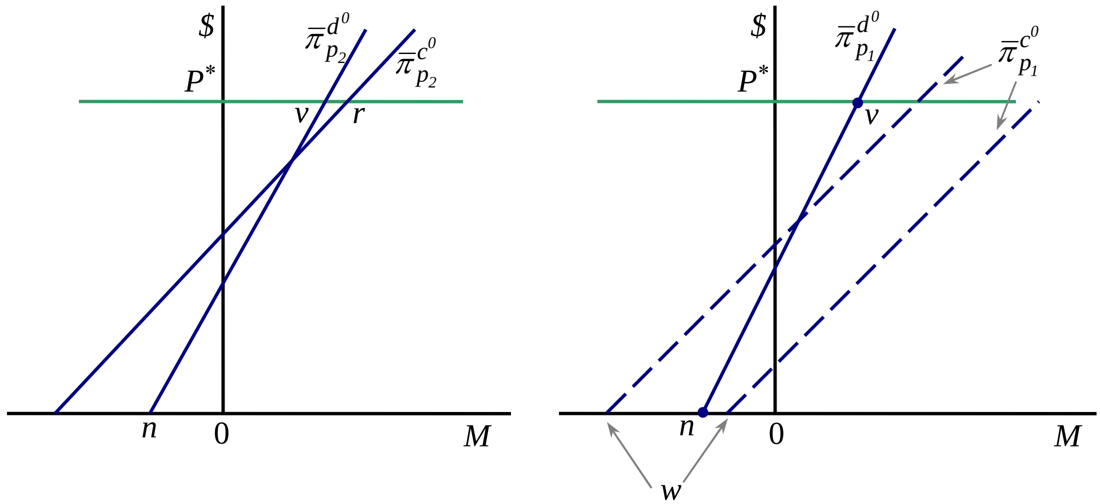


Figure 6.18 Comparing the alternatives of custom coefficients versus default coefficient in the case of a homogeneous PA

The right diagram in Figure 6.18 illustrates the case of a homogeneous PA formed with farmers from group s. The solution in the default coefficient can be any point in segment nv, while the solution in the custom coefficient case is located at point w. In order to assess the two coefficient alternatives, we compare the abscissas of points n and w. If $P^*\left[N_s\left(x_s - x_d\right) + N_l\left(x_l - x_d\right)\right] > C'^{c}_{m_1} - C'^{d}_{m_1}$ holds, the farmers will prefer the custom coefficients option, while if $P^*\left[N_s\left(x_s - x_d\right) + N_l\left(x_l - x_d\right)\right] < C'^{c}_{m_1} - C'^{d}_{m_1}$, the farmers will benefit more from the default coefficient alternative.

6.3.3 The coexistence of an FPA and a PA

As it is argued earlier in this chapter, the information costs and the monitoring costs will be much higher in the custom coefficients case compared to the default coefficient case. Monitoring activity can be very costly, especially when it needs to be performed in large and diverse areas. The aggregator might aggregate farmers that cover a large area in order to capture economies of scale. This might result in a large number of farmers aggregated under a pool, a variety of corresponding land types and a variation in the sequestration phase that farmers are in. The costs of undertaking monitoring for such an aggregation might become so costly and time consuming as to make the custom coefficients case uneconomical/unprofitable. Under these considerations, the alternative that would be applied by the aggregators would be the default coefficient case. The analysis below is performed for the default coefficient case.

Under the assumption of equal cost of adopting, let's consider what happens when the FPA and the PA are both in the market. While the PA breaks even, the FPA matches the prices (P_e and M) offered by the PA. If the FPA sets a lower M or offers a higher P_e, her profit will decrease, while if she sets a higher M or a lower P_e, the farmers will prefer to perform monitoring through their own pool either than using the FPA monitoring services. But, can the FPA still make profit by offering the same prices as the PA?

Using the isoprofit formulas (6.8) and (6.10) derived for the FPA and the PA, respectively, and considering the argument that the same prices are used by both aggregators, we obtain the following relation:

$$-\frac{C_m^d}{Nx_d}-\frac{\overline{\pi}_p^d}{Nx_d}=-\frac{C'^d_m}{Nx_d}-\frac{F}{Nx_d}$$

which can be rewritten as:

$$\left(C'^d_m-C_m^d\right)+F=\overline{\pi}_p^d.$$

The difference $\left(C'^d_m-C_m^d\right)$ indicates the difference in the monitoring costs incurred by a producers' association and a for-profit aggregator, respectively. The FPA can make a positive profit $\overline{\pi}_p^d>0$ only if $\left(C'^d_m-C_m^d\right)+F>0$. More specifically, the FPA can price the same as the PA and still make a profit only if the saving in the monitoring cost in the case of a PA compared to the case of a FPA, $\left(C_m^d-C'^d_m\right)$, is smaller than the cost of organizing the PA. If this saving in the monitoring cost is higher than the cost of organizing the pool, F, then the FPA cannot survive by pricing as the PA does; thus it will leave the market and the monitoring service will be provided to the farmers only through a pool of their own. Thus, the possibility of the coexistence of both structures for the aggregator in the market exists, but it is not a certainty.

6.4 CONCLUSIONS

This chapter has focused on the carbon offsets pooling and the heterogeneity that exists among farmers as to the amount of carbon that they sequester. The analysis looks upon two structures for the aggregator – a FPA and a PA – and it considers two alternatives for the coefficients that might be used to decide on the amount of carbon offsets each farmer will be entitled to for a payment. The two alternatives examined in the chapter are the custom coefficient and the default coefficient.

The analysis is first performed for the general case where the costs of adopting are considered as different for farmers belonging to different groups and is followed by the reasonable case where the cost of adopting are considered as equal.

The general case

The investigation begins by finding the coalition areas under each alternative as well as deriving the optimal inspection probabilities that ensure farmers' compliance. The incidence of being inspected is different for farmers from different groups; therefore monitoring is a targeted one.

After having explored the problem from the farmers' point of view, the analysis continues from the aggregator's perspective. The study considers two types of pools – heterogeneous and homogeneous – and examines which type of pool performs better under different alternatives.

In the case of an **FPA**, the aggregator selects the group of farmer to whom she offers he monitoring service. The FPA chooses the grouping that provides her the highest profit. As it might be expected, under both coefficient alternatives, the FPA would not consider doing the monitoring for a homogeneous group including farmers from group

s. The analysis shows that the for-profit structure will most likely lead to a homogeneous pool formed with farmers from the middle stage of sequestration.

In the case of a **PA**, the farmers decide whether they will form a heterogeneous or a homogeneous pool. The farmers will select the type of pool that provides them higher benefits.

In the *default coefficient* case, both groups of farmers benefit from the creation of a heterogeneous pool, but the farmers from group l benefit more than the farmers from group s. This is a result of the two-part tariff pricing which is the pricing strategy used in order to give incentives for participation to the farmers in the middle stage of sequestration.

In the *custom coefficient* case, both groups of farmers benefit from the formation of a heterogeneous pool, but which of the group benefits more depends on the bargaining and/or political power of the two groups.

Under both coefficient alternatives, the farmers in group l get the highest benefits from forming a homogeneous pool on their own. Under these circumstances, the farmers from group s will also consider forming a homogeneous pool of their own otherwise they can not sell their carbon offsets. Hence, the PA structure has potential to lead to the formation of a homogeneous pool assembling farmers in middle stage of sequestration and a homogeneous pool with farmers from group s.

The analysis then focuses on a *reasonable scenario* with equal cost of adapting for all farmers that undertake a BMP. The investigation shows that, in the default coefficient case, the FPA gets the same profit from offering the service to a homogeneous pool of either type as it gets from offering it to a heterogeneous pool. On the other hand, the analysis also indicates that the farmers benefit the same from the formation of a homogeneous pool of their own as they do from the establishment of a heterogeneous PA. Hence, the heterogeneous pool becomes stable under both the FP structure as well as the PA structure. It is also revealed that, under a PA structure, the farmers from each group benefit the same from the formation of a heterogeneous pool. In addition, the equalization of the inspection probabilities for each group of farmers shows that the PA will not undertake a targeted monitoring in the default coefficient case.

The results do not change when we perform the analysis for the reasonable scenario in the custom coefficients case.

The last section performs a comparison of the default coefficient alternative versus the custom coefficient alternative. The analysis finds the conditions under which the default coefficient or the custom coefficients option is preferred for each aggregator type. None of the two coefficient alternatives is absolutely favoured relative to the other.

The investigation in the last section is completed with the consideration of the coexistence of a FPA and a PA in the default coefficient case. The analysis show that both aggregators structures can exist together in the market at the same time only if the savings in the monitoring costs made possible by the PA are smaller than the cost of organizing the pool. If this condition is not satisfied the FPA cannot survive in the market and the structure that will dominate the market will be the producers' association formed by the farmers themselves.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Climate change issue has been a growing concern in the last two decades. Many countries have been considering different policy options to address climate change. One of the mechanisms suggested for mitigating climate change is carbon sinks. Agricultural communities have been excited about the potential of farmers obtaining credits for the carbon stored in their soil. However, one of the practical issues impeding the potential carbon offsets sales is monitoring and verification. Farmers need to be monitored in order to ensure that the carbon offsets that are claimed represent an actual reduction of carbon. Investigation of individual farmers is costly however. The costs associated with monitoring and enforcement may result in imperfect enforcement. Incomplete enforcement generates economic incentives for farmers to over-report the amount of carbon offsets they are claiming in order to obtain carbon credits.

This dissertation examines the cost effectiveness of the carbon-offset market when non-compliance is introduced in the economic analysis. Chapter II examines the nature of the carbon offsets and the role of agriculture as a potential contributor to the reduction of GHGs. A particular focus on this chapter is the land management practices that play a role in enhancing soil carbon retention. The adoption of these practices should be supported by policy designs that provide economic benefits to the farmers as well as encourage environmental benefits. The discussion in this chapter addresses the main issues that might complicate the policy design for agricultural soil carbon sequestration. Issues such as property rights and contract design, non-permanence, baseline establishment, and monitoring and verification will influence the level of incentives required to encourage producers' participation in the offset market as well as the efficiency of this market in reducing GHG emission. Chapter III examines the evolution of the environmental regulation and climate change literature with a particular focus on the efficiency property of the market-based instruments. The chapter then concentrates on the literature related to the carbon offsets option and compliance monitoring.

The thesis develops a number of theoretical models to examine the questions raised in the objectives of this thesis. The theoretical models examine the incentives for different farmers to participate in the carbon offsets market as well as incentives for engaging in cheating. Chapter IV examines the economic determinants of farmers' non-compliance as well as the consequences of non-compliance on the performance of the carbon-offset market. Chapter V examines the impact the involvement of the traders in the carbon-offset market has on non-compliance, as well as how the structure of the monitoring group affects non-compliance and the amount of carbon offsets traded in the market. Chapter VI examines the carbon offsets pooling option by considering two structures for the aggregator: a for-profit aggregator (FPA) and a producers' association (PA) and compares the alternatives of custom coefficients versus default coefficient for each aggregator type. The chapter examines as well which type of pool – a heterogeneous or a homogeneous one – performs better under different alternatives.

The models developed in Chapter IV and V recognize the heterogeneity of farmers with respect to cost differences as a result of differences in such things as soil type, experience, location, education and management skills. The individualized cost structure makes the analysis much richer, and provides valuable insights as to why some farmers sign a sequestration contract and others do not, and why some farmers engage in non-compliance activity and others do not. The model developed in Chapter VI captures another type of heterogeneity – the magnitude of sequestration that farmers can undertake – and examines how the aggregator will target the monitoring service for different group of farmers.

The theoretical models offer a number of insights with respect to non-compliance and carbon offsets trading. The results of the basic model replicate standard results in the cheating literature, which show that that the extent of farmers' participation in the carbon market and the share of farmers in non-compliance depend on the price of carbon offsets and the enforcement policy of the government. More specifically, the extent of non-compliance is shown to decrease with an increase in the audit probability and/or an increase in the per unit penalty. In addition, the number of farmers participating in the carbon-offset market is shown to increase with an increase in the carbon-offset price.

The total supply of carbon offsets as well as the supply of genuine carbon offsets is determined by the amount of monitoring performed by the monitoring agency. Endogenizing the monitoring probability allows us to make inferences about the efficiency of involving different traders and monitoring agencies in the intermediary role. The key role of the traders is to guarantee, based on the amount of monitoring undertaken by the monitoring group, that the LFEs purchase only carbon offsets that correspond to actual sequestration. The results produced in Chapter V show that the optimal amount of enforcement depends on the nature of the organization that undertakes the enforcement. The analysis investigates three cases for the monitoring group – a group owned by for-profit traders, a government-run agency, and a group owned by the PA trader. The results derived in the first two cases show that for-profit firms or the governmental agency undertake sufficient monitoring to ensure that full compliance is achieved – thus, while non-compliance is possible, it does not occur in equilibrium. A governmental agency will undertake more monitoring than a monitoring group owned by the firms. The more monitoring is undertaken from the monitoring group, the greater is the amount of the genuine carbon offsets in the market; hence the greater is the amount traded by the aggregators in the carbon-offset market. The finding suggests that an undertaking of monitoring by a governmental agency results in more trading activity as well as more genuine carbon offsets supplied in the market. Farmers are being paid a higher price per unit of carbon offset and emitters are paying a lower price for carbon offsets when the monitoring and trading of carbon offsets is performed via the governmental agency than by for-profit firms.

In the case of a PA, farmers produce carbon offsets which are traded through a collectively owned and managed producers association and monitored by a monitoring group that operates on behalf of the PA. Forming a PA enables the farmers to benefit from economies of scale associated with the fixed costs which will be shared among them. The PA can handle large volumes so that per unit monitoring costs can be kept low.

Because of the information asymmetry, the PA offers the same contract for all farmers, thus a pooled price applies in this model. As a result, farmers have incentive to behave strategically by free riding on the contribution of the others. More specifically, they try to benefit from price gains created by the pool without sharing in its costs.

The last part of Chapter V examines the manner in which the PA determines the pooling price and the probability of auditing and compares the results to those of the for-profit firms. For a given auditing probability, the PA's choice of the pooled price is made along an isorevenue curve which captures the tradeoff between a higher volume of bogus carbon offsets claimed by the farmers and a lower average price paid to them by the PA. The results show that under certain circumstances, the PA undertakes more monitoring and supplies more genuine carbon offsets in the market than does a for-profit trading company. In this case farmers sequester more carbon in their soil and LFEs pay a lower price for carbon offsets. The results obtained from the analysis in this chapter show that different structures considered for the trading sector and the monitoring group result in different trading activity, different prices at which offsets are traded as well as different levels of auditing. These results derive from the difference in the objective functions attributed to the different organizational structures considered in this chapter of the thesis.

Chapter VI focuses on the carbon offsets pooling and the heterogeneity that exists among farmers as to the amount of carbon that they sequester. Farmers may sequester different quantities of carbon at the same point in time for the same land size depending on which sequestration phase they are. Based on the timing of sequestration, farmers are categorized into one of two groups – (1) farmers who are in the early stage or farmers who are in the late stage of sequestration and sequester relatively small amounts of carbon in their soil, and (2) farmers that are in the middle stage of sequestration and sequester large amounts of soil carbon. The chapter considers the case of a pool owned and managed by the farmers in parallel to the case of an aggregator who runs the business on a for-profit basis. The situation is modeled in a principal agent framework. The principal, which is the aggregator, undertakes monitoring as well as the trading of carbon offsets in the market. The pricing schedule used by the aggregator is a two-part tariff. The two-part tariff is used as a way of providing an incentive for the farmers sequestering large amounts of carbon to participate in the pool.

The aggregator uses certain coefficients to determine the amount of carbon offsets for which each farmer is eligible for payment. This model considers two types of coefficients that could be used: a default coefficient under which all the farmers receive the same payment regardless of the sequestration stage in which they are, and custom coefficients under which the payment are linked to the stage of sequestration.

The study considers two types of pools - heterogeneous and homogeneous – and examines which type of pool performs better under different alternatives. In the case of a FPA, it is the aggregator who selects the group of farmer to which she is going to offer the monitoring service. In the more general case where the costs of adopting the BMP are different for farmers belonging to different groups, the investigation shows that the for-profit structure will most likely lead to a homogeneous pool formed with farmers from the middle stage of sequestration. In the reasonable scenario where the costs of adopting the BMP are considered to be equal for farmers in both groups, the analysis shows that the FPA gets the same profit from offering the service to a homogeneous pool of either type as it gets from offering it to a heterogeneous pool; thus a heterogeneous pool is stable.

In the case of a PA, the farmers decide whether they will form a heterogeneous or a homogeneous pool. In the more general case, when the default coefficient is used, both groups of farmers benefit from the creation of a heterogeneous pool, but the farmers that are in the middle stage of sequestration benefit the most. This is a result of the two-part tariff pricing used as a pricing schedule by the aggregator. For the reasonable case where the costs of adopting the BMP are considered to be equal for farmers in both groups, the analysis indicates that farmers from each group benefit the same from the formation of the heterogeneous pool.

In the more general case, when the custom coefficients are used, both groups of farmers benefit from the formation of a heterogeneous pool, but which of the group benefits more depends on the bargaining and/or political power of the two groups. This result is not altered when the case with equal costs of adopting is considered.

Farmers that are in the middle stage of sequestration will form a pool of their own in those cases where they were benefiting the most from a homogeneous pool. Under these circumstances, the farmers from the other group will also consider forming a homogeneous pool of their own otherwise they can not sell their carbon offsets. Hence, the PA structure may as well lead to the formation of a homogeneous pool assembling farmers in the middle stage of sequestration and a homogeneous pool with farmers from the other group.

Another consideration of this thesis is the comparison of the alternatives of custom coefficients versus default coefficient. The analysis finds the conditions under which the default coefficient or the custom coefficients option is preferred for each aggregator type. None of the two coefficient alternatives is absolutely favored to the other.

The last issue investigated in this dissertation is the coexistence of a FPA and a PA in the default coefficient case. The analysis show that both aggregator structures can exist together in the market in the same time if the savings in the monitoring costs made possible by the PA are smaller than the cost of organizing the pool. If this condition is not satisfied the FPA cannot survive in the market and the producers' association will dominate.

The objective of this study was to introduce cheating and costly enforcement into the economic analysis of the carbon offsets market. The use of a differentiating-characteristic model offered a number of insights. However, the model did not examine differences between farmers in their inclination to engage in cheating, even though it is a significant determinant of individual behaviour. The social norms and community pressure might also play a significant role in inducing compliance. Incorporating such attributes in the model could provide further valuable insights.

A subject of future interest would be to consider the case of an emitters association that would undertake the monitoring of carbon offsets and compare the efficiency of the carbon offsets market in this particular case to the cases considered in this dissertation.

Although the data on carbon offset market are still not available for an empirical work, a validation of the theoretical models developed in this thesis in the future would be of particular interest.

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APPENDIX

APPENDIX A4

MODELING LARGE FINAL EMITTERS' PROBLEM

The emitters' problem can be modeled similarly to the way farmers' problem was modeled. Large final emitters are required to take care of their emission released during the production activity. They can do this by the means of undertaking abatement or buying carbon offsets. We have opted out from trading among LFEs in order to concentrate on the carbon offsets alternative. LFEs are assumed to differ in such things as technology adopted, management abilities and experience and these differences affect their respective emission reduction costs. The basic model will be a location model that captures LFEs' heterogeneity regarding the costs of undertaking abatement. The analysis assumes that LFEs are uniformly distributed with respect to their differentiating characteristic. It is also assumed that each LFE is required to reduce emission by one unit.

Before investigating the LFEs' compliance decision, it is useful to analyze the LFEs' decision in a world where policy enforcement is perfect and LFEs take care of all their emissions. After exploring this case, the assumption of full-compliance will be released and the LFEs' decision on abatement, offsets purchasing and violation level will be investigated. The derivation of the demand for carbon offsets and some comparative statics finalize the work presented in this appendix.

A4.1 Large Final Emitters' Decision on Abatement and Offset Purchasing

This section is investigating the LFEs' decision in a perfect enforcement scenario. Consider a group of LFEs who produce an industrial product with carbon emissions as a by-product. The model captures emission reduction required over and above permitted amounts. LFE has two choices to address her emission reduction requirements: undertaking abatement or buying carbon offsets.

It is assumed that LFEs differ in their cost of undertaking the emission reduction. This cost difference gives rise to a demand for carbon offsets. Let $e \in [0,1]$ be the attribute that differentiates the LFEs. A large final emitter with attribute e has the following costs of emission reduction:

$C_A = C^0 + \beta e$ if the emission requirement is met by abatement

$C_o = P_e$ if the emission requirement is met by the purchase of a carbon offset

where C_A and C_o are the costs associated with abating one unit of emission and buying one unit of carbon offset, respectively. The parameter C^0 denotes the per unit abatement cost of the LFE with differentiating attribute $e = 0$. The parameter β is a nonnegative cost enhancement factor that is constant across all LFEs, while the term βe represents the additional cost incurred by LFEs with $e > 0$. To ensure non-negativity of the portion of LFEs that select the alternative of buying carbon offsets, it is assumed that $\beta \geq P_e - C^0$ (see equation A4.2).

A LFE's choice of whether to undertake abatement or to buy carbon offset is determined by the relationship between the costs associated with each option. Figure A4.1 illustrates the options available to LFEs and the costs of these options. The horizontal axis depicts the differentiating attribute e. The upward sloping curve C_A graphs the cost associated with undertaking abatement for different values of the differentiating attribute (i.e., for different LFEs), while the horizontal line C_o shows the cost of buying carbon offsets in the market. The intersection of the two cost curves determines the level of the attribute corresponding to the LFE indifferent between the two options. Specifically, the LFE with differentiating attribute e_o given by:

(A4.1) $$e_o : C_A = C_o \Rightarrow e_o = \frac{P_e - C^0}{\beta}$$

is indifferent between undertaking abatement or buying carbon offsets since the cost associated with the two options are the same. LFEs located to the left of e_o (i.e., LFEs with $e \in [0, e_o]$) find it less costly to undertake abatement, while LFEs located to the right of e_o (i.e., LFEs with $e \in (e_o, 1]$) find it more profitable to buy carbon offsets.

Recalling that LFEs are uniformly distributed with respect to their differentiating characteristic e, the level of e corresponding to the indifferent LFE, e_o, also determines the fraction of LFEs that decide to undertake abatement. The portion of LFEs that choose to buy carbon offsets is given by $1 - e_o$. By normalizing the mass of LFEs at unity, the proportion of LFEs that select to buy carbon offsets gives the demand for carbon offsets, x^d, which is written as follows:

(A4.2) $x^d = \dfrac{\beta - \left(P_e - C^0\right)}{\beta}$

The inverse demand curve can be written as $D_0 : P_e = \left(C^0 + \beta\right) - \beta x^d$.

Comparative statics results can be easily derived from the graph. A reduction in P_e shifts the C^0 curve downwards, thus increasing the demand for carbon offsets (i.e., $\dfrac{\partial x^d}{\partial P_e} < 0$). A decrease in the cost enhancement factor β causes a rightward rotation of the C_A curve through the intercept at C^0, which in turn decreases the demand for carbon offsets (i.e., $\dfrac{\partial x^d}{\partial \beta} > 0$).

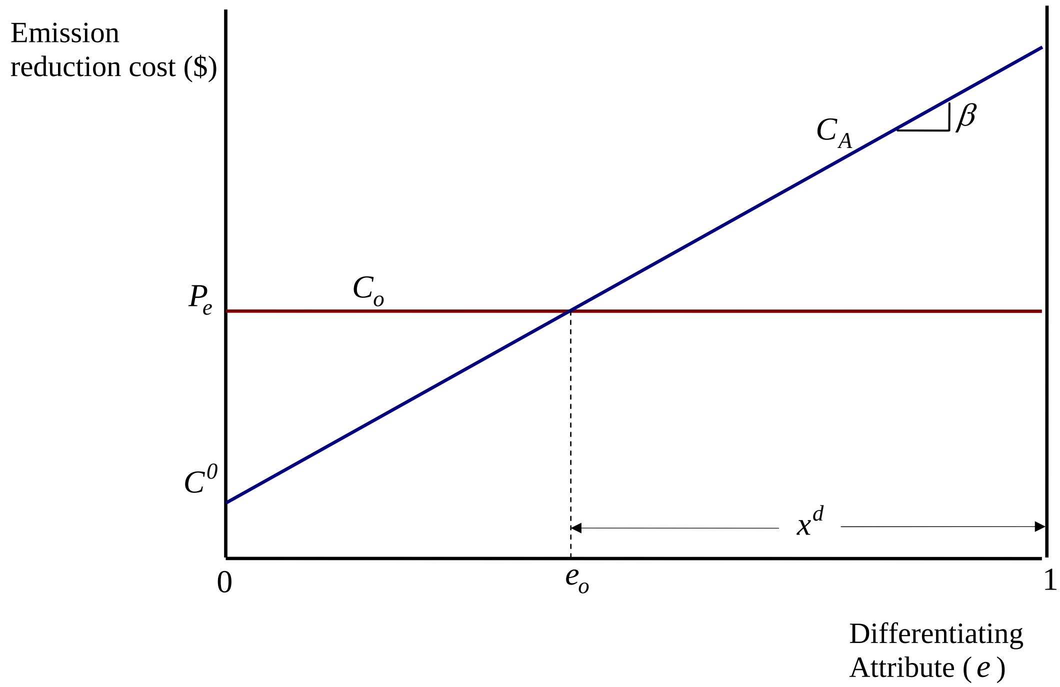

Figure A.4.1 LFEs' decision under perfect compliance

A4.2: Extending the Basic Model: Introducing Non-Compliance on the Large Final Emitters' Side

Implicit in the above analysis is the assumption that either (1) LFEs do not cheat when reporting their emission; or (2) enforcement is perfect and costless. Enforcement, however, requires resources. The consequence of the resource costs of monitoring and enforcement might be a lack of enforcement activity, which in turn creates economic incentives for LFEs to underreport their emission levels. Under these circumstances, each LFE can meet her emission reduction target by the choice of one of three options: undertaking abatement; reporting abatement that was not undertaken (i.e., cheating); and buying carbon offsets in the offset market.

Assume that LFEs know the probability $\delta \in [0,1]$ that they will be investigated, detected and punished, as well as the per-unit penalty ρ for detected non-compliance.

In case a LFE violates the emission level, her expected cost will depend on her probability of being investigated, the penalty in case she is caught cheating and her personalized cost of engaging in cheating. This cost, which is denoted by $\tau e,$ can be the result of trying to masquerade emission violation. The parameter τ is a non-negative cost enhancement factor which is constant across all LFEs. Each LFE who cheats incurs this cost regardless of being detected or not. The cost of engaging in cheating follows the same pattern as the cost of emission reduction since the more expensive abatement is the more difficult masquerading emission violations becomes. If an LFE is not detected, she saves the abatement cost of reducing her emission by one unit or the cost of buying one unit of carbon offset. The expected cost of cheating for a LFE with attribute e who reports abatement that is not undertaken (i.e., underreports emissions) is given as follows:

(A4.3) $C_c = \delta\rho + \tau e$

Note that since LFEs differ with respect to $e,$ and as a result in their personalized cost of cheating, the expected costs of cheating differ across LFEs.

The LFE's decision of whether to undertake abatement, buy carbon offsets or cheat is determined by comparing the costs associated with each of the three options. A graphical illustration of the LFE's decision is given in Figure A4.2. The intersection of curves C_A and C_c determines the level of the differentiating characteristic e_1 :

(A4.4) $e_1 : C_A = C_c \Rightarrow e_1 = \dfrac{\delta\rho - C^0}{\beta - \tau}$

corresponding to the LFE who is indifferent between undertaking abatement and cheating. Similarly, the intersection of curves C_o and C_c determines the level of the differentiating characteristic e_2 :

(A4.5) $e_2 : C_c = C_o \Rightarrow e_2 = \dfrac{P_e - \delta\rho}{\tau}$

corresponding to the LFE indifferent between buying carbon offset and cheating.

LFEs positioned to the left of e_1 (i.e., LFEs with $e \in [0, e_1]$) choose to undertake abatement, while those positioned between e_1 and e_2 (i.e., LFEs with $e \in (e_1, e_2)$) underreport their emissions; LFEs located to the right of e_2 (i.e., LFEs with $e \in [e_2, 1]$) select to buy carbon offsets.

Assuming that LFEs are uniformly distributed with respect to the differentiating attribute e, the level of e_1 determines the fraction of LFEs who abate, $(e_2 - e_1)$ gives the fraction of LFEs that engage in cheating, and $(1 - e_2)$ determines the portion of LFEs that buy carbon offsets.

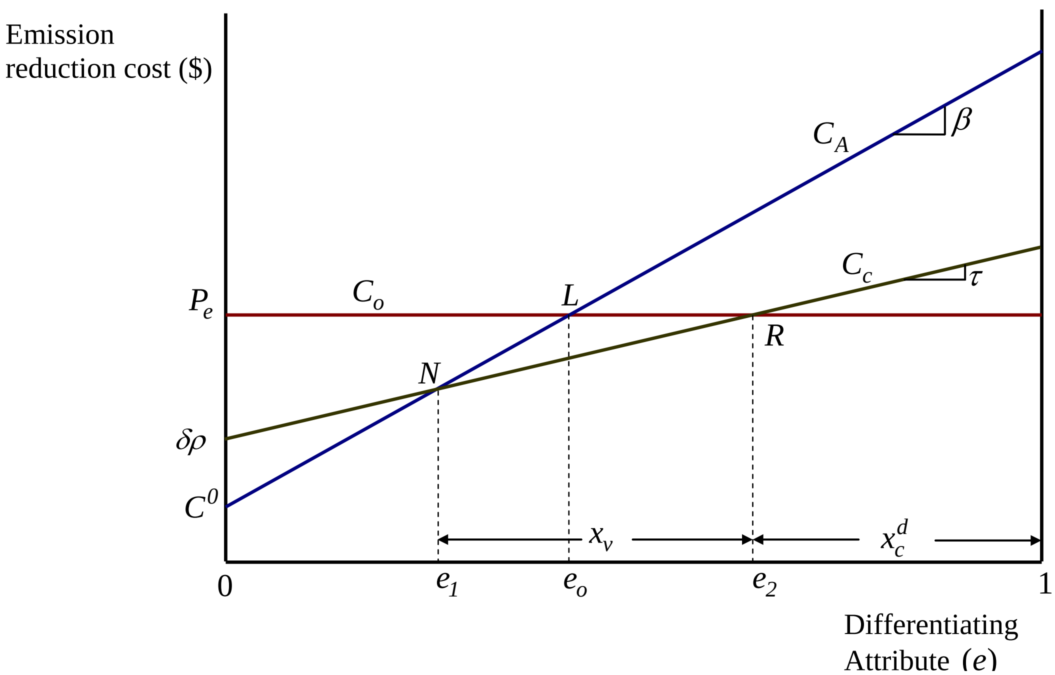

Figure A4.2 LFEs' decision under imperfect compliance

Since the mass of LFEs is normalized at unity, the fraction of LFEs that decide to buy carbon offsets gives the LFEs' demand for carbon offsets, $x_c^d = 1 - e_2$, which can formally be written as follows:

(A4.6) $x_c^d = \dfrac{\tau - (P_e - \delta\rho)}{\tau}$.

The inverse demand for carbon offsets can be written as $D: P_e = (\tau + \delta\rho) - \tau x_c^d$. For simplicity of notation we denote the expression $(\tau + \delta\rho)$ by η and we use this in the main body of the thesis.

The level of abatement undertaken is presented by $x_a = e_1$, which can be written as:

(A4.7) $x_a = \dfrac{\delta\rho - C^0}{\beta - \tau}$

and the amount of abatement violations is given by $x_v = e_2 - e_1$, where x_v is given by:

(A4.8) $x_v = \dfrac{P_e - \delta\rho}{\tau} - \dfrac{\delta\rho - C^0}{\beta - \tau} = \dfrac{(P_e - \delta\rho)\beta - (P_e - C^0)\tau}{\tau(\beta - \tau)}$

The model analyses the LFE's decision when all three choices are available. Assume we have an interior solution so that all three variables x_a, x_v, x_c^d are positive. This assumption needs the following conditions to hold: in order to have $x_a > 0$, $C^0 \leq \delta\rho$ should hold (see equation A4.7); in order to have $x_v > 0$, $\beta > \dfrac{(P_e - C^0)}{(P_e - \delta\rho)}\tau$ should hold (see equation A4.8); and in order to have $x_c^d > 0$, $\tau \geq (P_e - \delta\rho)$ should hold (see equation A4.6). From equation A4.8 we can derive the critical audit probability value $\delta^{cr} = \dfrac{P_e\beta - (P_e - C^0)\tau}{\beta\rho}$, for which the full compliance holds (i.e., $x_v = 0$). For audit probabilities $\delta \geq \delta^{cr}$, non-compliance will be completely deterred. Each LFE selects either to undertake abatement or to buy carbon offsets; she does not find underreporting profitable since the probability of being detected is too high.

The inverse demand curves for a perfect compliance scenario as well as for the non-compliance case are illustrated in Figure A4.3 as curves D_0 and D, respectively. Referring to Figure A4.2, we can derive the condition under which $(e_2 - e_1) = 0$ (i.e. points N and R converge to L). This happens when carbon offset price is $P_e = \frac{(\delta\rho)\beta - C^0\tau}{\beta - \tau}$. Thus, both demand curves join for prices less than $\frac{(\delta\rho)\beta - C^0\tau}{\beta - \tau}$.

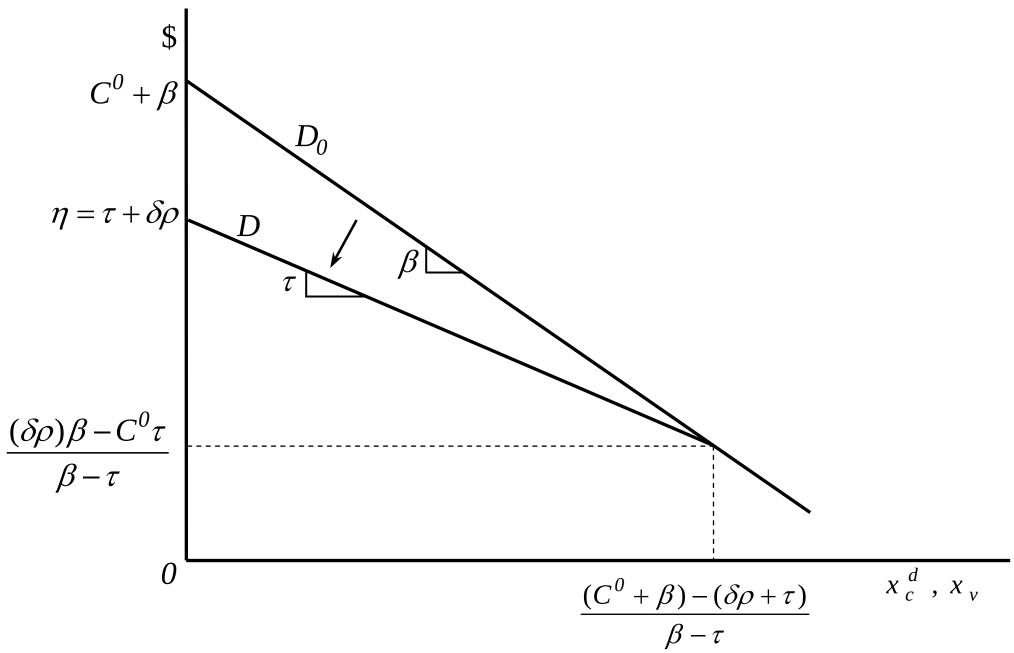

Figure A4.3 Demand curves under both scenarios

Comparative static results can be derived from Figure A4.2. For instance, an increase in the price of carbon offsets will influence the number of LFEs that buy carbon offsets or engage in cheating behaviour. Specifically, the level of cheating will increase while, at the same time, the demand for carbon offsets will turn out to decrease (i.e., $\frac{\partial x_c^d}{\partial P_e} < 0, \frac{\partial x_v}{\partial P_e} > 0$).

An increase in the penalty per unit of violation causes an upward shift of the curve C_c that decreases the violation level and increases the fraction of LFEs that purchase carbon offsets (i.e., $\frac{\partial x_c^d}{\partial \rho} > 0, \frac{\partial x_v}{\partial \rho} < 0$). Similarly, an increase in the audit probability δ shifts the curve C_c upward, thus decreasing the violation level and increasing the demand for carbon offsets (i.e., $\frac{\partial x_c^d}{\partial \delta} > 0, \frac{\partial x_v}{\partial \delta} < 0$).

A4.3 Conclusions

This appendix develops a model of heterogeneous LFEs to derive the demand for carbon offsets as well as to examine the impact of non-compliance on the demand side. The investigation starts with a perfect compliance situation to continue after with the consideration of the demand side when non-compliance on LFEs' side is introduced in the analysis.

The comparative statics results show that the extend of LFEs non-compliance increases with an increase in the price of carbon offsets and decreases with an increase in the audit frequency and/or an increase in the penalty per unit of cheating.

APPENDIX A5

Appendix 5.1 Monopoly Case:

Stage 2: The maximization problem for the trader:

The objective function:
$$Max_{Y,X}\, PY - P_e(Y + X)$$
$$st \quad Y \le \overline{Y}$$

where P is given by: $D : P = \eta - \tau Y = \eta - \tau \dfrac{\theta\gamma}{\varphi}$

and P_e is given by: $S_0 : P_e = \lambda Y = \lambda \dfrac{\theta\gamma}{\varphi}$.

Lagrangean function: $L = PY - P_e(Y + X) + \kappa(\overline{Y} - Y)$

The first-order Kuhn-Tucker conditions with respect to the choice variables Y, X and the Lagrangean multiplier κ for this problem are:

(**A5.1.1**) $L_Y = \dfrac{\partial L}{\partial Y} = P + \dfrac{\partial P}{\partial Y} Y - P_e - \dfrac{\partial P_e}{\partial Z}(Y + X) - \kappa \le 0 \qquad Y \ge 0 \rightarrow L_Y Y = 0$

(**A5.1.2**) $L_X = \dfrac{\partial L}{\partial X} = -P_e - \dfrac{\partial P_e}{\partial Z}(Y + X) \le 0 \qquad \mathrm{X} \ge 0 \rightarrow \mathrm{L_X} X = 0$

(**A5.1.3**) $L_\kappa = \dfrac{\partial L}{\partial \kappa} = \overline{Y} - Y \ge 0 \qquad \kappa \ge 0 \rightarrow L_\kappa \kappa = 0$

The second condition holds as a strict inequality, hence $X = 0$. We can have two solutions:

(1) if $Y > 0,\ X = 0,\ \kappa = 0,$ then

$$L_Y = 0 \to P + \frac{\partial P}{\partial Y}Y - P_e - \frac{\partial P_e}{\partial Y}Y = 0 \to \underbrace{P + \frac{\partial P}{\partial Y}Y}_{MR_m} = \underbrace{P_e + \frac{\partial P_e}{\partial Y}Y}_{MO_m}.$$

The solution is determined by $MR_m = MO_m$ and formally is written as follows:

$$Y_m = \frac{\eta}{2(\tau + \lambda)}; \quad X = 0; \quad \kappa = 0.$$

(2) if $Y > 0,\ X = 0,\ \kappa > 0,$ the constraint is binding. The solution will be:

$$\bar{Y} = \frac{\theta\gamma}{\varphi}; \quad X = 0; \quad \kappa = \eta - 2(\tau + \lambda)\frac{\theta\gamma}{\varphi}.$$

As shown in Chapter V, the output will be the lesser of Y_m and $\bar{Y}$.

Stage 1: Maximization problem for the monitoring group owned by the monopolist

The objective function: $$Max_{\theta}\ P\frac{\theta\gamma}{\varphi}-P_e\frac{\theta\gamma}{\varphi}-\frac{1}{2}\xi\theta^2$$

After substituting P and P_e from the demand and supply equations, the First Order Condition with respect to θ can be written as follows:

$$\frac{\partial(\pi-C_m)}{\partial\theta}=\eta\frac{\gamma}{\varphi}-2\tau\left(\frac{\gamma}{\varphi}\right)^2\theta-2\lambda\left(\frac{\gamma}{\varphi}\right)^2\theta-\xi\theta=0$$

In Y-space, this condition would be written as:

$$\underbrace{\eta-2\tau Y}_{MR_m}=\underbrace{2\lambda Y}_{MO_m}+\underbrace{\xi\frac{\varphi^2}{\gamma^2}Y}_{C_m^{'}}.$$

Therefore, the optimal amount of monitoring is determined by: $MR_m=MO_m+C_m^{'}$, which formally is written as shown below:

$$\theta^*=\frac{\eta\varphi\gamma}{2(\tau+\lambda)\gamma^2+\xi\varphi^2}.$$

This optimal monitoring defines the position of the genuine carbon offsets, thus defines $\bar{Y}$. Substituting this expression instead of θ into the formula for $\bar{Y}$ we get:

$$\bar{Y}^*=\frac{\eta\gamma^2}{2(\tau+\lambda)\gamma^2+\xi\varphi^2}$$

Appendix 5.2: Oligopoly Case

Stage 2: Maximization problem for each oligopolistic trader:

$$\underset{y_i, x_i}{Max}\ \pi_i = P(y_i + y_{-i})y_i - P_e \underbrace{(y_i + x_i + y_{-i} + x_{-i})}_{Z}(y_i + x_i)$$

$$st \quad y_i + y_{-i} \le \overline{Y} \qquad\qquad i \in \{1, ..., N\}$$

The Lagrangean function can be written as:

$$L = P(y_i + y_{-i})y_i - P_e(y_i + x_i + y_{-i} + x_{-i})(y_i + x_i) + \kappa_i(\overline{Y} - y_i - y_{-i})$$

The first-order Kuhn-Tucker conditions with respect to the choice variables y_i, x_i and the Lagrangean multiplier κ_i for this problem are:

(A**5.2.1**) $$L_{y_i} = \frac{\partial L}{\partial y_i} = P + \frac{\partial P}{\partial Y}y_i - P_e - \frac{\partial P_e}{\partial Z}y_i - \frac{\partial P_e}{\partial Z}x_i - \kappa_i \le 0 \qquad y_i \ge 0 \rightarrow L_{y_i}y_i = 0$$

(A5.2.**2**) $$L_{x_i} = \frac{\partial L}{\partial x_i} = -P_e - \frac{\partial P_e}{\partial Z}x_i - \frac{\partial P_e}{\partial Z}y_i \le 0 \qquad x_i \ge 0 \rightarrow L_{x_i}x_i = 0$$

(A5.2.**3**) $$L_{\kappa_i} = \frac{\partial L}{\partial \kappa_i} = \overline{Y} - y_i - y_{-i} \ge 0 \qquad \kappa_i \ge 0 \rightarrow L_{\kappa_i}\kappa_i = 0$$

Condition (A5.2.2) holds as a strict inequality therefore $x_i = 0$. We can have two solutions:

(1) if $y_i > 0,\ x_i = 0,\ \kappa = 0,$ we proceed as follows:

$$L_{y_i} = 0 \rightarrow P + \frac{\partial P}{\partial Y}y_i = P_e + \frac{\partial P_e}{\partial Z}y_i$$

By substituting P and P_e from the demand and supply equations, the solution can be written as follows:

$$y_i = \frac{\eta - (\tau + \lambda) y_{-i}}{2(\tau + \lambda)},\ x_i = 0,\quad \kappa = 0.,$$

After considering the symmetry of the firms, we get the amount traded by each firm given by the formula:

$$y_i = \frac{\eta}{(\tau + \lambda)(N + 1)}$$

while the total amount of carbon offsets traded by all firms is given by:

$$Y_o = \frac{\eta N}{(\tau + \lambda)(N + 1)}$$

So, the solution in this case is:

$$Y_o = \frac{\eta N}{(\tau + \lambda)(N + 1)};\quad X = 0;\quad \kappa = 0.$$

(2) if $y_i > 0,\ x_i = 0,\ \kappa > 0,$ the constraint is binding. Thus: $y_i + y_{-i} = \bar{Y} = \dfrac{\theta\gamma}{\varphi}$

Because of the symmetry of the firms we get the following:

$$y_i = \frac{\bar{Y}}{N} = \frac{\theta\gamma}{N\varphi}$$

By using the above equation as well as the condition (A.2.1), we get the formula for the shadow value as follows:

$$\kappa_i = \eta - \frac{\theta\gamma(\tau + \lambda)(N + 1)}{\varphi N}$$

The solution in this case would be:

$$\bar{Y} = \frac{\theta\gamma}{\varphi},\ X=0,\ \kappa_i = \eta - \frac{\theta\gamma(\tau + \lambda)(N + 1)}{\varphi N}.$$

As argued in Chapter V, the amount traded by oligopoly will be the lesser of Y_o and $\bar{Y}$.

Stage 1: Maximization problem for the monitoring group owned by the oligopolistic firms

The objective function: $Max_{\theta}\ P\frac{\theta\gamma}{\varphi} - P_e\frac{\theta\gamma}{\varphi} - \frac{1}{2}\xi\theta^2$

It is exactly the same as in the monopoly case, therefore the optimal auditing probability is given by the same formula:

$$\theta^* = \frac{\eta\varphi\gamma}{2(\tau+\lambda)\gamma^2 + \xi\varphi^2}$$

This optimal monitoring defines the position of the genuine carbon offsets, thus defines $\bar{Y}$. Substituting this expression instead of θ into the formula for $\bar{Y}$ we get:

$$\bar{Y}^* = \frac{\eta\gamma^2}{2(\tau+\lambda)\gamma^2 + \xi\varphi^2}$$

This is determined by the relation $MR_m = MO_m + C_m^{'}$.

Appendix 5.3: Governmental Agency

<u>Stage 1: Unconstrained maximization problem for the monitoring group:</u>

Monitoring group maximizes the social welfare minus the monitoring cost which, in terms of Y, would be expressed as follows:

$$W = \pi + CS + PS - C_m = \int_0^{\bar{Y}} [\eta - \tau Y] dY - \int_0^{\bar{Y}} \lambda Y dY - \frac{1}{2}\xi \left(\frac{\bar{Y}\varphi}{\gamma}\right)^2$$

$$= \eta \bar{Y} - \tau \frac{\bar{Y}^2}{2} - \lambda \frac{\bar{Y}^2}{2} - \frac{1}{2}\xi \left(\frac{\bar{Y}\varphi}{\gamma}\right)^2$$

In terms of θ, the objective function of the monitoring group will be written as follows:

$$Max_\theta \; W = Max_\theta \; \eta \frac{\theta\gamma}{\varphi} - \tau \frac{(\theta\gamma)^2}{2\varphi^2} - \lambda \frac{(\theta\gamma)^2}{2\varphi^2} - \frac{1}{2}\xi\theta^2$$

The First Order Condition for this problem specification is:

$$\frac{\partial(W)}{\partial\theta} = \eta \frac{\gamma}{\varphi} - \tau \left(\frac{\gamma}{\varphi}\right)^2 \theta - \lambda \left(\frac{\gamma}{\varphi}\right)^2 \theta - \xi\theta = 0$$

In Y-space, this condition would be written as follows:

$$\underbrace{\eta - \tau Y}_{D} = \underbrace{\lambda Y}_{S_0} + \underbrace{\xi Y \frac{\varphi^2}{\gamma^2}}_{C_m^{'}}$$

This means that the first order condition is satisfied at the point where $D = S_0 + C_m^{'}$.
The optimal amount of monitoring is given by the formula:

$$\theta^* = \frac{\eta\varphi\gamma}{(\tau + \lambda)\gamma^2 + \xi\varphi^2}.$$

This optimal monitoring defines the position of the genuine carbon offsets, thus defines $\bar{Y}$. Substituting this expression instead of θ into the formula for $\bar{Y}$ we get:

$$\bar{Y}_{uc}^* = \frac{\eta\gamma^2}{(\tau + \lambda)\gamma^2 + \xi\varphi^2}.$$

APPENDIX A6

Finding $-M_3$ and P_{e_3} :

$-M_3 = ?$

$-M_3 : IR_s^{c^0} \cap IR_l^{c^0}$

$$\frac{C^{a'}(x_s)}{x_s} + \frac{1}{x_s}M = \frac{C^{a'}(x_l)}{x_l} + \frac{1}{x_l}M$$

$$-M_3 = \frac{C^{a'}(x_l)x_s - C^{a'}(x_s)x_l}{x_l - x_s}$$

From $\mathrm{IR}_s^{c^0}$ we want to find: $P_{e_3} = ?$

$$P_{e_3} = \frac{C^{a'}(x_s)}{x_s} + \frac{1}{x_s}\frac{C^{a'}(x_l)x_s - C^{a'}(x_s)x_l}{x_l - x_s}$$

$$P_{e_3} = \frac{C^{a'}(x_l)x_s - C^{a'}(x_s)x_s}{x_s(x_l - x_s)}$$

Finding M_n :

$M_n : \overline{\pi}_p^{d^0} \cap P_e = 0$

$$0 = P^* - \frac{C_m^{'d} + F}{Nx_d} + \frac{1}{x_d}M$$

$$M_n = -\left(P^* x_d - \frac{C_m^{'d} + F}{N}\right)$$

Finding M_v :

$M_v : \overline{\pi}_p^{d^0} \cap P_e = P^*$

$$P^* = P^* - \frac{C_m^{'d} + F}{Nx_d} + \frac{1}{x_d}M$$

$$M_v = \frac{C_m^{'d} + F}{N}$$

Finding M_t :

$$M_t : \overline{\pi}_p^{c^0} \cap P_e = 0$$

$$0 = P^* - \frac{C_m^{'c} + F}{N_s x_s + N_l x_l} + \frac{N}{N_s x_s + N_l x_l} M$$

$$M_t = -\left(\frac{P^*\left(N_s x_s + N_l x_l\right)}{N} - \frac{C_m^{'c} + F}{N} \right)$$

Finding M_w :

$$M_w : \overline{\pi}_{p_1}^{c^0} \cap P_e = 0$$

$$0 = P^* - \frac{C_{m_1}^{'c} + F}{N_s x_s + N_l x_l} + \frac{N}{N_s x_s + N_l x_l} M$$

$$M_w = -\left(\frac{P^*\left(N_s x_s + N_l x_l\right)}{N} - \frac{C_{m_1}^{'c} + F}{N} \right)$$

Finding M_r :

$$M_r : \overline{\pi}_{p_2}^{c^0} \cap P_e = P^*$$

$$P^* = P^* - \frac{C_{m_2}^{'c}}{N_s x_s + N_l x_l} + \frac{N}{N_s x_s + N_l x_l} M$$

$$M_w = \frac{C_m^{'c} + F}{N}$$

The coordinates of point j :

$$j : IR_s^c \cap \overline{\pi}_p^{c^0}$$

$$\frac{C^{a'}\left(x_s\right) + \Delta'}{x_s} + \frac{1}{x_s} M = P^* - \frac{C_m^{'c} + F}{N_s x_s + N_l x_l} + \frac{N}{N_s x_s + N_l x_l} M$$

$$M_j = \frac{\left[P^* x_s - C^{a'}\left(x_s\right) - \Delta'\right]\left(N_s x_s + N_l x_l\right) - \left(C_m^{'c} + F\right) x_s}{x_s\left(N_s x_s + N_l x_l\right) - N x_s}$$

$$P_{e_j} = P^* - \frac{\left(C_m^{'c} + F\right)}{N_s x_s + N_l x_l} + \frac{N}{N_s x_s + N_l x_l} \frac{\left[P^* x_s - C^{a'}\left(x_s\right) - \Delta'\right]\left(N_s x_s + N_l x_l\right) - \left(C_m^{'c} + F\right) x_s}{x_s\left(N_s x_s + N_l x_l\right) - N x_s}$$

Comparing M_n to M_w :

$$M_n = \frac{C'^{d}_{m_1} + F}{N} - P^* x_d \; ? \; \frac{C'^{c}_{m_1} + F}{N} - \frac{P^*\left(N_s x_s + N_l x_l\right)}{N} = M_w$$

$$M_w > M_n \text{ if } P^*\left[N_s\left(x_s - x_d\right) + N_l\left(x_l - x_d\right)\right] < C'^{c}_{m_1} - C'^{d}_{m_1}$$

$$M_w < M_n \text{ if } P^*\left[N_s\left(x_s - x_d\right) + N_l\left(x_l - x_d\right)\right] > C'^{c}_{m_1} - C'^{d}_{m_1}$$